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Report from the Sub-Committee for Considering Standard Methods for Salinity Determination

By

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At the meeting of the ICES in Paris, October 1954, the Council adopted the following recommendation from the Hydrographical Committee: — "It is recommended that a Sub-Committee of five be established to consider the revision of the present standard method of salinity determination by the Oxner-Knudsen method as described by Helge THOMSEN in the *Bulletin de l'Institut Océanographique* of Monaco. It is also recommended that provision be made for this Sub-Committee to meet if necessary, prior to the next assembly of the Council, in order that it may report at that assembly".

The sub-committee consists of Messrs. F. HERMANN (Chairman, Denmark), K. KALLE (Germany), F. KOCZY (Sweden), J. LONGWELL, later replaced by W. MANIECE (Great Britain), and P. TCHERNIA (France).

An *ad hoc* sub-committee of the Hydrographical Committee had considered that the standard method should be reviewed in view of the fact that a number of deviations are in general use in the different countries. This committee also suggested that it would be useful, if the sub-committee could collect information about methods other than titration for salinity determination and about experience with polyethylene bottles for storage of sea-water samples.

An inquiry asking for information about these points was sent to the members of the Hydrographical Committee and to Prof. MIYAKE, Japan, Dr. ROCHFORD, Australia, and Prof. Thomas G. THOMPSON, USA. Contributions received in reply to this inquiry are summarized in the review at the end of this report. The contributions were circulated to the members of the sub-committee and discussed by correspondence. The sub-committee then met at Charlottenlund from 21. to 23. October 1955.

A preliminary report was prepared most of which is included in the present report. The report was laid before the Hydrographical Committee at the Council meeting and the following recommendation was carried: —

Rec. 2. "The Hydrographical Committee after considering the report of its sub-committee recommends that: —

(a) A new description of the Mohr-Knudsen procedure should be worked out as a standard method for the routine determination of salinity. The description should include the modifications that are in general use and have been

shown not to reduce the accuracy of the method, namely the use of magnetic stirrer and fluorescein indicator. The description should also include a specification of the burette and pipette to be used.

(b) The sub-committee which was appointed in 1954 to consider the revision of the method should continue and draw up the standard method for final publication."

Furthermore the committee recommended that steps be taken to get the loan of a Wenner bridge for salinity determinations in order to gain experience with the method at one of the institutions that takes part in the work of the Council. Consequently the sub-committee continued its work.

After discussion of the contributions received in answer to the inquiry the sub-committee came to the following conclusions: —

1. The essential requirements of any method for the routine determination of salinity are simplicity, speed, and accuracy. From the point of view of simplicity and speed the Mohr-Knudsen method is most convenient and gives an accuracy of $\pm$ 0·02 $^0/_{00}$ S.

2. The Mohr-Knudsen method can be modified to increase speed by use of mechanical, especially magnetic, stirring without loss of accuracy.

3. The chromate indicator of the Mohr-Knudsen method can be replaced by fluorescein sodium with a slight increase in accuracy. The titration with these modifications are described later in this report.

4. A limiting factor in the accuracy of a titration method is the volumetric error. A major increase in accuracy cannot be expected unless this is reduced, for example by weighing the sample or treating the glassware with repellent coating. For a routine method, weighing cannot be used and treatment with silicone water repellents has not in general been found satisfactory.

5. To facilitate the detection of the end point certain laboratories are using a potentiometric endpoint, which has the advantage of increasing precision or reducing eyestrain associated with colorimetric methods. Potentiometric methods are of greatest application in non-routine work, where the samples are weighed, but they could be used for routine work in so far as they reduce fatigue of the operator. These methods do not, in general, increase the speed of the determination. A potentiometric end point has been used in an Automatic Chlorinity Titrator (ACT) developed in the USA. This instrument requires a well-trained operator.

6. A micro method has been devised by Miss SARUHASHI in Japan. This involves titration with silver nitrate using fluorescein sodium indicator, but requires only one-tenth of the quantities of sample and reagent as the Mohr-Knudsen method. It is fast and accurate, but hardly as accurate as the standard method, as the micro method gives greater volumetric errors.

7. Determination of salinity by means of density, electrical conductivity, and refractive index measurements have been developed, but only the density methods of COX and KALLE and the conductivity method of WENNER *et al.* give the required accuracy of $\pm$ 0·02 $^0/_{00}$ combined with sufficient speed. A modification of the Wenner bridge has been constructed at Woods Hole Oceanographic Institution (SCHLEICHER and BRADSHAW, 1956) and looks very promising. An accuracy of 0·008 $^0/_{00}$ S and a speed of 20 determinations per hour was reported. Unfortunately it was impossible to get this instrument on loan to test at one of the laboratories in a member country of ICES as the only two existing instruments are in constant use. Another modification of the Wenner bridge

has recently been built at the National Institute of Oceanography, England. According to Dr. Cox both precision and speed are at least as good as in the Woods Hole instrument.

The advantages of the conductivity methods are evident. They are free from the volumetric errors which limit the accuracy of most titration methods and seem to be relatively quick and simple in handling, both at sea and in the laboratory. Furthermore the method is the only means by which accurate continuous recording of salinities can be obtained *in situ*.

The sub-committee is, however, of the opinion that the effect of solubility of glass on conductivity and constancy of the chlorinity-conductivity relationship over wide areas should be further studied to make sure that no systematic deviation occurs between salinities calculated from chlorinity determinations and salinities calculated from conductivities. The solubility of glass is also a serious disadvantage for the density methods. Thomas G. THOMPSON has demonstrated that long-time storage in soft glass bottles could cause an increase in density of as much as 0·08 in σ_0 corresponding to an error in salinity of $0{\cdot}10\,^0/_{00}$ (Th. G. THOMPSON and H. E. WIRTH, 1931).

8. Experience with polyethylene bottles has shown that they are unsatisfactory for the storage of sea-water samples.

The Sub-Committee wish to express their thanks to all the people who have assisted them in their work.

Procedure of the Mohr-Knudsen Titration

The Mohr-Knudsen titration is a titration of the halogen ions in sea water with silver nitrate using potassium chromate as indicator. The chemical reactions are as follows: —

$$Cl^- + Ag^+ \rightarrow Ag\,Cl \qquad (1)$$

$$CrO_4^{--} + 2Ag^+ \rightarrow Ag_2CrO_4 \qquad (2)$$

As soon as all the chloride ions are precipitated and a small surplus of silver ions is added the red silver chromate is formed. A faint trace of red then indicates the end point where all halogen ions are precipitated.

The silver nitrate solution is standardized against the international standard sea water, which is natural sea water diluted with a little distilled water to obtain a chlorinity of about $19{\cdot}38\,^0/_{00}$. The chlorinity of this standard is determined with an accuracy of $0{\cdot}001\,^0/_{00}$ Cl by "Dépôt d'Eau Normale", Charlottenlund Slot, Charlottenlund, Denmark, which is producing and selling standard sea water in sealed hard glass ampoules.

Definition of chlorinity

This method, which is described in detail below has been employed as the standard method by the ICES since 1902. The use of standard sea water should secure that all chlorinity determinations were directly comparable independent of time and place. The chlorinity of the standard sea water on which all other chlorinities are based is determined by comparison by a modified Volhard method with a primary standard. The chlorinity of the first primary standard sea water was determined by SØRENSEN in 1900 by comparing it with a solution

of pure potassium chloride and by weight analyses. SØRENSEN (1902) adopted the following definition of chlorinity: "By chlorinity is understood the mass of of chlorine equivalent to the total mass of halogen contained in the mass of 1 kilogramme of sea water".

In 1937 a new primary standard sea water or "urnormal" was prepared (JACOBSEN and KNUDSEN, 1940). Its chlorinity was determined partly by comparison with the first primary standard and partly by gravimetric titration with "Atomgewichtssilber" carried out by Prof. HÖNIGSMID in Munich.

The two sets of determinations showed a difference which was due to the fact that the atomic weights used by SØRENSEN in 1900 were different from those internationally adopted in 1938. In order to secure comparability between older and future determinations the chlorinity value 19·381 $^0/_{00}$ obtained by comparison with the first primary standard was adopted for "Urnormal 1937". This value is 0·0077 smaller than the value found by HÖNIGSMID based on the 1938 atomic weights.

The following new definition, which is independent of changes in values of atomic weights, was adopted for chlorinity of sea water: "The number giving the chlorinity in per mille of a sea-water sample is by definition identical with the number giving the mass in grammes of 'Atomgewichtssilber' just necessary to precipitate the halogens in 0·3285234 kg of the sea-water sample". A small supply of "Atomgewichtssilber" is stored at Charlottenlund for future control of the primary standard.

The salinity of a sea-water sample can be found from its chlorinity from the Hydrographical Tables (M. KNUDSEN, 1901). It is defined by the equation: $S = 0{\cdot}030 + 1{\cdot}8050 \times Cl$ and is practically identical with the weight in g of salts dissolved in one kg of the sea water when all carbonates are converted to oxides, and bromine and iodine replaced by the equivalent amount of chlorine.

Solutions and glassware

Silver nitrate. A solution of 37·11 g pure silver nitrate per litre distilled water filtered through filter paper into an amber glass bottle of suitable capacity, e.g., 8 litres.

Potassium chromate. 20 g pure potassium chromate dissolved in 250 ml distilled water.

Standard sea water is delivered from "Dépôt d'Eau Normale", Charlottenlund Slot, Charlottenlund, Denmark in ampoules containing about 250 ml. The chlorinity of this standard is about 19·38 and is given to 3 decimal places. The points of the ampoule are cut by means of a glass knife and a 300 ml bottle washed carefully twice with small amounts of the sea water and then filled from the ampoule. If drops of sea water adhere to the inner side of the neck, they should be carefully removed with filter paper. The bottle is closed with a good rubber stopper with two holes. One hole is connected to a washing bottle containing sea water and the other supplied with a glass tube reaching near the bottom of the bottle and with a piece of rubber tubing on the upper end. This rubber tube is closed with a glass rod.

The distilled water used for solutions and for washing the titration vessel should be tested for chloride ions by adding a little silver nitrate solution to a sample of it. If it remains clear the water is sufficiently pure.

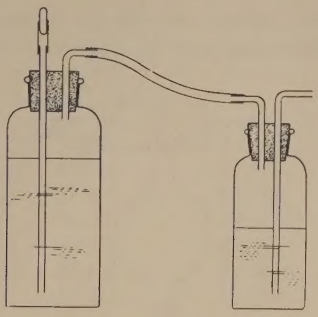

Figure 1. Bottle for storage of standard sea water.

Knudsen pipette and burette

(a) *Knudsen pipette.* This pipette is designed for quick and accurate measuring of 15 ml of the sea-water sample. An automatic zero point is obtained by a two-way stopcock. It is filled by sucking through branch B and emptied by turning the stopcock to connect with air valve A. It is not necessary to know its volume with great accuracy. The outflow time should be about 30 seconds (Fig. 2).

(b) *Knudsen burette.* By the Knudsen burette the volume of silver nitrate solution used for the titration is measured. In order to reduce the surface to volume ratio as much as possible and thus minimize the effect of drainage it is shaped as a ball burette (Fig. 3). It is filled through stopcock A, which is connected with the silver nitrate bottle, the two-way stopcock B establishes an automatic zero point, just as in the pipette. The silver nitrate is run into the titration vessel through stopcock C.

The unit of division is double ml, for oceanic samples a range of 17 to 20 d ml is convenient with divisions to 0·01 d ml. For Mediterranean samples a range of 18 to 22 d ml is the best, and for coastal water a common burette with or without automatic zero stopcock can be used.

It is advisable to calibrate the burette by weighing the amount of silver nitrate measured off. As it is unimportant if the unit for the burette is exactly 1 d ml this unit can be chosen so the correction round 19·4, i.e., round the reading for a standard sea-water titration, is zero. The burette should be read after exactly the same time as used at the titrations and the temper-

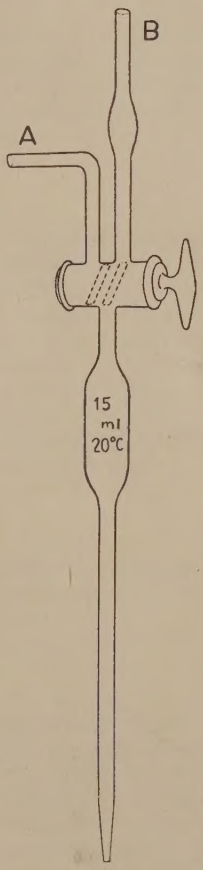

Figure 2.
The Knudsen pipette.

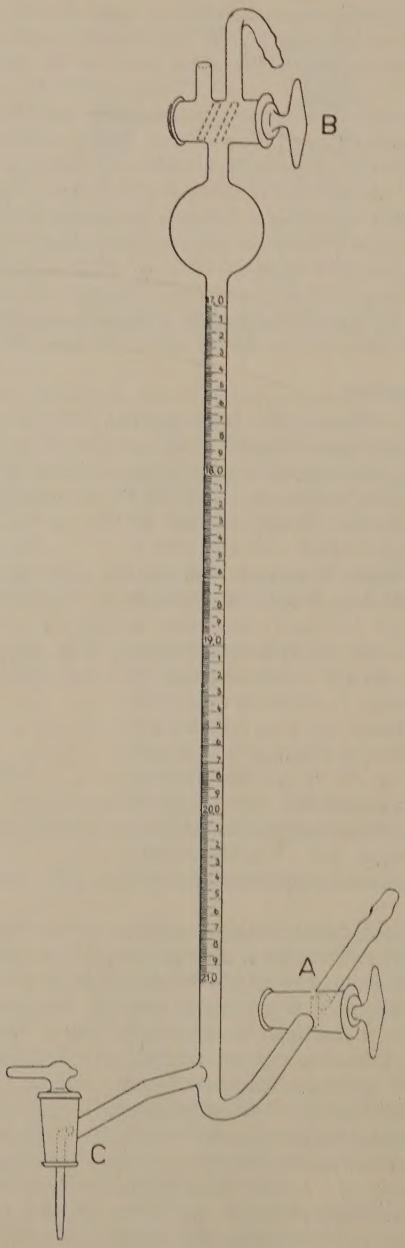

Figure 3. The Knudsen burette.
Divisions: 17 to 21 d ml in 1/100 d ml. Length of division: 1 d ml = about 10 cm.

ature of the silver nitrate should be constant within 0·2°C during the calibration. An example of calculating these relative corrections is shown below.

Reading of burette d ml	Amount of $AgNO_3$ sol. g	Number of units	Relative corrections d ml
17·047	35·100	17·060	+0·013
17·506	36·044	17·518	+0·012
18·010	37·075	18·019	+0·009
18·562	38·216	18·574	+0·008
19·011	39·120	19·013	+0·002
19·520	40·160	19·519	−0·001
19·938	41·015	19·934	−0·004

Unit used 2·0575 g $AgNO_3$

For the reading of the burette the Menaché loupe (MENACHÉ, 1950) is very convenient. If this is not available a milk glass plate screwed on a wooden clamp should be placed behind the menisc. The edge of the wooden clamp should always be placed in the same distance below the meniscus. The burette can then be read by means of a common magnifying glass.

Cleansing of burettes and pipettes

In order to keep drainage errors to a minimum it is essential that burette and pipette are completely clean. A very effective cleaning method is that proposed by KING (1950). The burette or pipette is filled with a 8% solution of NaOH in methyl alcohol, after about 5 minutes it is emptied and when as much as possible of this solution has run off it is rinsed with concentrated nitric acid followed by rinsing with distilled water and regreasing of stopcocks. The pipette stopcock and the upper stopcock of the burette should be greased with glycerine, the two lower burette stopcocks with stopcock grease. Silicone grease was found to be very good. Only a very small quantity of grease should be applied in order to avoid the deposit of lumps of grease in the bore.

Titration vessel

For titration with hand stirring a conical flask of the following dimensions can be used: base diameter 5 cm, upper diameter 7 cm, height 10 cm.

Titration with hand stirring

Measurement of the sea-water sample

The water sample is shaken and the pipette is washed twice with about 5 ml of the sample by sucking through branch B and emptying through the same branch. The tube of the pipette must be wiped carefully with a clean linen cloth each time it has been dipped in the water. Thereafter it is sucked full of the water, the stopcock is closed and the pipette is emptied into the titration beaker by turning the stopcock so the air valve is connected with the pipette. During this procedure the pipette is held vertically with the tip just above the water surface. After drainage the surface of the water is just touched twice with the tip of the pipette to secure that the same amount of water is left in the pipette each time. Five drops of the potassium chromate are then added by means of a pipette.

Titration with silver nitrate

The bottle containing the silver nitrate is shaken carefully and the burette is washed with the silver nitrate by emptying and filling it three times.

The outlet tip is then wiped with filter paper and the titration vessel placed below it. The upper stopcock is turned to make connexion with the air and the outlet stopcock is opened, so that the silver nitrate is added in a fine stream which should run down the sloping surface of the glass just above the liquid. By means of a glass rod the liquid is quickly stirred, care being taken to avoid splashing. A red tint will gradually appear where the silver nitrate strikes the liquid. When this red spot has increased to form a nearly closed ring the silver nitrate stream is reduced to a dropwise addition. At the same time the stirring is made quicker to break the formed clots of silver chloride. The dropwise addition is continued till all the liquid has a faint but definite red colour. At this point the addition is stopped, the flask is rotated while the liquid by means of the rod is brought into contact with all the inner surface of the glass in order to wash down any splashes. Then the liquid is stirred vigorously with the rod for 15 seconds to break the precipitate. The chloride ions occluded in the precipitate will now cause the colour to change back to yellow. Finally small fractions of silver nitrate drops are added by means of the rod till the liquid has a faint orange colour. This is the final end point of the titration. The burette is read after exactly the same time after the beginning of silver nitrate addition, e.g. after $2\frac{1}{2}$ minutes. It is essential that all titrations are carried out in the same way and that the colour at the end point always is the same.

For each ten titrations a titration is carried out on standard sea water. The pipette is filled through the rubber tubing on the standard sea water bottle. In order to judge the end point accurately it is important to have a good and constant illumination on the titration glass.Fluorescent daylight lamps placed above the titration table have been found to be very good and also illumination from below gives good results (ESCHEMANN, 1942).

Titration with mechanical stirring

Alternatively the liquid during the titration can be stirred mechanically, preferably by some form of magnetic device. The titration vessel is a beaker of approximate dimensions 6·5 cm × 5 cm diameter. A small magnet 4 cm × 0·7 cm diameter coated with polythene rests on the bottom of the beaker and is rotated by means of an external magnet attached to a motor. The titration beaker stands on the motor assembly which can either stand on or be incorporated in the work bench. The sample is pipetted into the beaker and indicator solution added as described above. The stirring motor is started at lowest speed (about 300 r.p.m.) and silver nitrate solution added from the burette in a thin stream. The burette tip must be placed excentric over the beaker and as low as convenient in order to avoid splashing. The addition of silver nitrate is continued until the red colour forms a half circle on the surface of the liquid. After that it is continued dropwise with a higher rate of stirring (about 500 r.p.m.) until the liquid is faint red. The stirring is now continued for about 45 seconds during which the colour changes back to yellow. In the meantime a new sample can be pipetted off in another beaker. The final end point is then reached by adding fractions of silver nitrate drops by means of a glass rod until

the liquid has a faint orange colour. The burette should be read after exactly the same time at each titration, e.g., 3 minutes. By this method about 15 titrations can be made per hour.

Titration with uranine-starch indicator and magnetic stirring

The uranine (fluorescein sodium) indicator, together with starch as a protective colloid was first used in titration of sea water by MIYAKE (1939). The protective colloid inhibits flocculation of particulate silver chloride. This increases the solid-liquid interface enormously which facilitates the ionic exchange. This means that the accuracy depends less on the rate and manner of stirring than in the Mohr method and that the titration can be carried out quickly. The uranine is an organic dye which is adsorbed on the surface of silver chloride suspensions on which the adsorbed Cl^- ion is replaced by Ag^+ ion at the stoichiometric end point (LANDINGHAM, 1957).

The colour of the indicator changes from green-yellow to pink at the end point.

Indicator. 1% starch solution is prepared by adding distilled water to 1 g soluble starch to form a thin paste which is slowly added to 100 ml boiling distilled water. The boiling is continued about 1 minute. After cooling 5 ml of a 1% uranine solution is added. A fresh indicator solution should be prepared every day.

Titration. The sample is pipetted into the beaker by means of the Knudsen pipette. The sea water remaining in the tip of the pipette is brought into the beaker by gently blowing in the air valve while the tip is held against the glass side. Afterwards the pipette is hung aside vertically. One millilitre of the indicator is then added and the beaker placed on the magnetic stirrer under the outlet of the burette. The burette tip must be placed eccentric over the beaker and as low as convenient in order to avoid splashing.

The magnetic stirring is now started, the lowest speed (about 300 r.p.m.) being sufficient and the silver nitrate is added in a thin stream. Where the silver nitrate mixes with the sample a red spot is seen indicating local surplus of silver ions. The addition of silver nitrate with the stopcock full open is continued until the red spot forms a nearly closed ring, thereafter it is continued dropwise until the end point is passed and the liquid is definitely red. The last drop of sea water, which in the meantime has collected in the tip of the pipette is now added by gently blowing in the air valve while the tip is held against the side of the glass just above the liquid. The colour will then shift back to yellow-green. The titration is now continued by adding fractions of drops of silver nitrate by means of a spatula until the colour is very faint red. This is the final end point.

With a little routine this titration can be carried out in 1 minute 45 seconds. In order to reduce the effect of drainage it is, however, advisable first to read the burette after 3 min. from the beginning of the addition of silver nitrate. This time must be the same at all the titrations and must be controlled by stop-watch. The glass can be washed and the next sample measured off while waiting to read the burette. It is advisable to use two titration glasses so the plastic covered magnet can be removed from the titrated sample, washed and transferred to the empty and clean glass.

The end point is very sharp and rather sudden, but with the method of the

last drop from the pipette it is easy to approach it slowly. This method also reduces the volumetric error of the pipette.

From double titrations on 26 samples a standard deviation of 0·004‰ Cl was calculated.

With this method it is possible to make 19 titrations per hour. It is advisable to make a small pause each hour. The titration can be carried out in the same way with hand stirring instead of magnetic stirring.

Necessary precautions

The standard sea water and the water samples must have the same temperature during the titration. A temperature difference of about 2°C may give an error in chlorinity of about 0·01‰ so the temperature difference should be less than 1°C. It is advisable to place both water samples and standard sea water in the titration room at the same level the day before the titrations are carried out.

Temperature changes in the silver nitrate solution will cause a similar error and should be avoided.

When the standard sea-water bottle is nearly empty the chlorinity of its content should be compared with that of a new ampoule of standard sea water by titration.

The tip of the burette should be greased with silicone grease to avoid adhesion of the silver nitrate solution.

Calculation of Chlorinity

The concentration of the silver nitrate is chosen so that the reading on the burette is nearly the same as the chlorinity of the sample so only a small correction need be added. This correction is found by means of the Hydrographical Tables by Martin KNUDSEN (1901). The chlorinity is the chloride concentration in weight promille but the titration is in principle a determination of chloride per volume. The effect of the variation of density with chlorinity has been included in the correction k given in the Hydrographical Tables. It is emphasized that these tables are based on the application of a standard sea water of chlorinity of about 19·38‰. Application of the tables in connexion with a standard essentially different from this can lead to serious errors as described by MENACHÉ (1950). By interpolation the Hydrographical Tables can be used with an accuracy of 0·003‰ Cl. Instead of the tables the slide rule constructed by KALLE (KALLE, 1955) can be used. If greater accuracy is required the method and table given by MENACHÉ (1954) can be used.

Review of Reports Received by the Sub-Committee

Australia

Titrations. Mohr-Knudsen method used with magnetic stirrer as only amendment.

Other methods. A temperature-salinity-depth recorder has been developed by Mr. B. V. Hamon (1956), Division of Electrotechnology, C.S.I.R.O., with the following ranges and accuracies: —

Temperature:	0°–30°C	± 0·1°
Cl‰:	18·3 –20·5	± 0·03‰
Depth:	0 –1,000 m	± 20 m

The temperature measuring element is a thermistor, the salinity element a conductivity cell with platinum electrodes, and the pressure element a Bourdon tube actuating a potentiometer. The resistance of the measuring elements influences in sequence the frequency of an oscillator, which transmits information through a single core cable to the shipboard unit. Measurements every 30 seconds.

A chainomatic pycnometer has been developed for coastal water (Rochford, 1954).

Belgium

Titration by the Mohr-Knudsen method is used.

Great Britain

Government Chemist

Titrations. The Mohr-Knudsen method with a magnetic stirrer is used. Christie and Newman compared hand and magnetic stirring and concluded that the use of magnetic stirrer reduces fatigue and increases output without altering the results.

The sodium fluoresceinate (uranine) indicator has been tried, but was found more tiring and less accurate than the potassium chromate method.

Experiments are going on with potentiometric titration by the Bather and Riley method. Application of silicone repellents on burettes and pipettes was found unsatisfactory.

Department of Oceanography, University of Liverpool

A high accuracy potentiometric method was worked out. A platinum indicator electrode and a mercury-mercurous sulfate reference electrode was used in conjunction with a magic eye voltmeter for end-point detection. For precise measurements the water sample was weighed, and the silver nitrate was measured volumetrically. Accuracy about 0·001‰ Cl (Bather and Riley, 1953).

Experiments of the change of salinity of sea water samples in polythene bottles showed that it is not permissible to store the water in such bottles for more than 14 days.

National Institute of Oceanography

Titration methods. An adsorption indicator consisting of 1 ml 1% soluble starch and 0·05% sodium fluorescein was preferred to potassium chromate

especially as it changes at the isoelectric point and is easier to use for people colour-blind in the red. There is a little difference in judging the end point.

The Bather and Riley technique with a modified circuit was used. This method increases the accuracy in judging the end point and relieves strain on the operator. Silver electrodes were found unreliable. Magnetic stirring was used in conjunction with this method.

Water repellent coatings were used on both pipettes and burettes with success. The standard deviation of tap pipettes were tested and were found to be 0·0057 to 0·0068 ml for unsiliconed and 0·0008 to 0·0026 ml for siliconed pipettes. It was further found that glycerol lubrication reduces accuracy as compared with grease lubrication. A grease of the following formula was found useful: Polyvinyl alcohol 5 g, Mannitol 20 g, Glycerol 100 g.

The influence of temperature differences on samples was investigated and it was found that a difference of 1°C at room temperature could cause an error in salinity of 0·01‰.

With the potentiometric method, siliconed glassware, and temperature precautions it was found possible to analyse 12 to 15 samples an hour with an accuracy of 0·01‰ S.

Salinity determinations by other means than titration. A method with direct measurements by electrode potentials is in the experimental stage. Silver/silver chloride electrodes are used.

An electrical conductivity meter has been constructed according to information from R. A. Cox (1958).

It is a development of the Woods Hole instrument (SCHLEICHER and BRADSHAW, 1956) with eight similar conductivity cells immersed in an oil-filled thermostat maintained at 10°C. One cell contains standard sea water, the remaining the unknown samples. The conductances of the samples are in turn compared with that of the standard on a special transformer bridge, which is supplied by an oscillator at 1700 cycles/sec.

Final figures for the precision cannot yet be given, but was estimated to about ±0·003‰ S. It was estimated that 30 salinities could be determined per hour.

Direct density measurements. R. A. Cox (1954a) has developed an apparatus, where the density of a float can be regulated by regulating the pressure above the water. The density of the water is calculated from the pressure at equilibrium.

Two modifications are now being tried, one to adapt the apparatus to work at sea and the other to make the float less fragile and more reproduceable.

Polythene bottles. R. A. Cox (1954b) has shown that a considerable evaporation takes place through the walls of polythene bottles, so these bottles should not be used for storage of samples for salinity determination.

Royal Naval Scientific Service

An instrument for the continuous measurement and recording of salinity in sea water.

The measuring element, which can be lowered down to 300 feet, consists of an electronic oscillator, radio frequency conductivity tube, and temperature measuring devices. The electrical currents from the measuring circuits are fed through a multi-core cable to the recorder on board the ship. The recorder has

the three distinct salinity ranges: 10–20‰, 20–30‰, and 30–40‰. Checks showed that the maximum error was less than 0·25‰.

Marine Biological Association, Plymouth

Titrations. Shallow water samples are sent to the Government Chemist. Fluorescein indicator was found to give a sharper end point than chromate.

It is proposed to use the Bather and Riley potentiometric titration for deeper ocean samples.

Polythene bottles. Loss in weight between 28 mg and 8 mg in 46 hours was found to be mainly due to breathing between neck and stopper. For bottles with waxed necks a loss in weight of $\frac{1}{3}$ mg per day was found.

In the Water Pollution Research Laboratory the standard Mohr-Knudsen method is used with the magnetic stirrer.

Denmark

For samples from inshore waters (lightships, coastal stations) hydrometers are used for salinity measurements. Accuracy about 0·2‰ S.

For other samples the Mohr-Knudsen method with magnetic stirrer is used. It is found that use of magnetic stirrer increased speed and relieved strain without altering accuracy.

Silicone water repellent coating on pipettes and burettes has been tried, but given up on account of necessity for frequent recoating.

The sodium fluoresceinate was tried and found to give a sharp end point. It is now used in the routine analyses.

For deep water samples a potentiometric titration is used (HERMANN, 1951), with silver/silver nitrate reference electrode and silver indicator electrode. Both the amount of sea water and of strong silver nitrate are determined by weighing. Accuracy 0·0015‰ Cl. It is found necessary to control the potential of electrodes at intervals.

In the preparation of Standard Sea Water a Volhard procedure is applied (JACOBSEN and KNUDSEN, 1940).

Finland

The Mohr-Knudsen method is used with special burettes of range 0 to 7·5 d ml.

France

In the Institut des Pêches the Mohr-Knudsen method is used with small modifications in the burettes.

In the Navy Chemical Laboratory the Mohr-Knudsen method is used with the improvements of the magnetic stirrer and of the fluorescein indicator. Standard Knudsen burettes and pipettes made by Richter & Wiese are used.

Germany

Experiments have been carried out for several years to improve the salinity determination.

From theoretical considerations for ocean waters the following table was drawn up: —

Method	Percentage sensitivity required to give an accuracy of $\pm 0{\cdot}02\,‰$ S	Necessary accuracy of temperature, °C
Cl-titration	0·05	2·3
Density	0·0015	0·06
Refraction of light	0·0003	0·04
Electrical conductivity	0·04	0·024
Velocity of sound	0·0012	0·009

To the standard Mohr-Knudsen method the following improvements have been added: —

(1) Illumination of the titration beaker from underneath, which makes it easier to recognize the sudden change of colour (ESCHEMANN, 1942).

(2) Development of a circular slide rule for reading of the salinity values from the titration values (KALLE, 1955).

Experiments with interferometer dipping refractometer and electrical conductivity did not give satisfactory results.

Density methods are after titration least dependent on temperature, and work was concentrated on these methods. An apparatus was developed with the following qualities: —

Accuracy 0·01–0·02‰ S.
About 40 ml water needed.
Quick method of operation.
Range 0–40‰ S.

The apparatus consists of a 7 ml glass float in the water sample in an insulated glass vessel. The float is suspended by means of a woman's hair in a two-armed torsion balance. The measuring accuracy is 0·01‰ S. Balance reading and temperature are converted to salinities by means of a nomogram. Errors due to surface tension on the hair are eliminated by adding a few drops of a distilled water solution of a detergent into the liquid surface (KALLE, 1955).

Experiments with *polythene bottles* have shown that these bottles permit vapour to pass through.

Iceland

The Mohr-Knudsen method is used with uranine indicator.

Japan

The Mohr-Knudsen method with uranine (sodium fluoresceinate) indicator is generally used. The indicator is a mixed solution of 5 ml 0·1% uranine and 100 ml 1% starch solution. One or two ml is added to 15 ml sea water. It was found that this method saved time and increased accuracy.

Japanese standard sea water standardized against Copenhagen standard sea water was used.

A micro method devised by Miss K. SARUHASHI (1954) used only a tenth of the volume of the standard method and uranine indicator. It was found to save much time and silver nitrate. An automatic titrator with a potentiometric end point using platinum-calomel electrodes is being tested. Silicone resin is used to avoid adhesion of water at tips of burettes and pipettes.

Pylythene bottles are not used for salinity samples.

Netherlands

The standard Mohr-Knudsen method is used. In addition, a micro-titration method is used at the Zoological Station, Den Helder. At the Oceanographic Department of the Meteorological Institute an electrical recording salinometer has been developed and used successfully. This instrument measures conductivity and compensates automatically for temperature variations. The accuracy of the latter two methods being smaller than the standard method, their use has been confined to coastal waters (DORRESTEIN, 1954).

Norway

The standard Mohr-Knudsen method is used. Magnetic stirrer is applied at two of the institutes.

Portugal

Standard Mohr-Knudsen method has been used.

Sweden

In the titrations three different types of burettes are used, all of them with Derona zero point.

For

Oceanic water: Knudsen Derona burette, range 16·5 to 22·5 d ml div. 1/100 d.
Transition water: Knudsen Derona burette, range 10 to 20 d ml div. 1/50 d.
Baltic water: Knudsen Derona burette, range 0·5 to 10 d ml div. 1/50 d.

The last with calibration scale between 19 and 20 d ml for standard sea water titration. Stopcocks are greased with silicone resin.

The magnetic stirrer and the sodium fluoresceinate-starch indicator are used giving an increase in both accuracy and speed. The accuracy of pipettes was tested and found to be 0·005 ml to 0·003 ml. KROGH's syringe pipettes were tried with success. The Bechmann desicote (silicone repellent) was tried without success on both burettes and pipettes. The pipettes had to be recoated every day.

For illumination a special arrangement with a daylight fluorescent lamp is used.

On three of the Swedish lightships salinities are determined by means of the Petterson immersed chain pycnometer.

Polythene bottles were tried. It was found that the increase in chlorinity was only 0·003 $^0/_{00}$ Cl during three months.

U. S. A.

Report from Thomas G. Thompson, University of Washington

The standard Knudsen method is used for salinity determinations. Very accurate determinations of electrical conductivity and refractive index have been made by THOMAS, THOMPSON, and UTTERBACK (1934). Both methods were found undesirable for routine determinations of salinity because of the errors produced by changes in temperature.

The micro method of SARUHASHI will be tested.

It has been found that evaporation takes place through *polythene bottles*. For storage of water samples "magnesium citrate" bottles are used.

Report from E. H. Smith, Woods Hole Oceanographic Institution

An improved modification of the Wenner bridge (WENNER, SMITH, and SOULE, 1930), which has been used for many years on the ships of the International Ice Patrol, has been built at Woods Hole Oceanographic Institution by Karl E. SCHLEICHER and Alvin BRADSHAW. The salinity of an unknown sample is determined by comparing its conductivity with that of a sample of known salinity at the same temperature. Six glass conductivity cells are placed in a constant temperature bath. One cell is filled with a substandard sea water, the others with the unknown samples. The reference cell and one of the sample cells are placed in adjacent arms of a 1000 cycles impedance bridge with a balancing mechanism to complete automatically the "fine" adjustment in bridge balance. The instrument was calibrated empirically. The precision was found to be better than $\pm 0{\cdot}005\,^0/_{00}$ S. The final accuracy including calibration errors is estimated to $\pm 0{\cdot}01\,^0/_{00}$ S at $35\,^0/_{00}$, descreasing to $\pm 0{\cdot}03\,^0/_{00}$ S or better at $30\,^0/_{00}$ S and $40\,^0/_{00}$ S. Twenty measurements could be made per hour (SCHLEICHER and BRADSHAW, 1956).

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The Direct Estimation of Ammonia in Sea Water with Notes on "Reactive" Iron, Nitrate, and Inorganic Phosphorus

By

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The Estimation of Ammonia

Dr. W. R. G. ATKINS in the June 1957 issue of this Journal (ATKINS, 1957) drew attention to the necessity for a rapid method for the direct determination of ammonia in sea water, a method not requiring distillation or other methods of separation. He pointed out the possibilities inherent in the pyrazolone technique originated by KRUSE and MELLON (KRUSE and MELLON, 1952 and 1953).

We have critically examined most of the published methods for the direct determination of ammonia in sea water. The procedure given by BULJAN (1951) held great promise but for reasons that we cannot understand this method was a complete failure in our hands. The Kruse and Mellon method, however, has been found to be applicable to sea water, with slight modifications, and appears to us to be superior in speed, accuracy, and precision to any other method so far described. A brief account of the technique will be given here and very complete working details may be obtained from *Standard Methods of Seawater Analysis*, Vol. 2 (STRICKLAND, 1958) obtainable from the Pacific Oceanographic Group, Nanaimo, B. C., Canada.

Reagents

De-ionized water should always be used, distilled water being passed through a small column of Dowex 50 or a similar resin in the hydrogen form immediately before use.

Carbon tetrachloride. Analytical reagent quality material is satisfactory.

Pyridine. Analytical reagent grade pyridine has been found to be satisfactory but this may not always be the case. Other sources are generally useless. The

reagent should be distilled with a few drops of bromine, using a fractionating column, and collecting the fraction boiling in a 2–3°C range near to 113°C (uncorrected). Unsuitable pyridine is easily recognized because a strong blue-green colour develops in the sea water before extraction whereas little or no colour is found in the carbon tetrachloride layer (see below).

Bis (3-methyl-1-phenyl-5-pyrazolone) (Bis reagent). This compound is obtainable as Eastman-Kodak 6969, 3-3′-dimethyl-1-1′-diphenyl-[4,4′-bi-2-pyrazoline]-5-5′-dione or can easily be prepared as described by Kruse and Mellon (1953).

Chloramine-T solution. 5% in de-ionized water, stable for not more than one to two weeks.

3-methyl-1-phenyl-5-pyrazolone solution (Mono reagent). Recrystallize this substance once from hot water, and prepare an 0·25% solution in de-ionized water. Stable indefinitely.

Pyrazolone reagent. Prepare immediately before use (storing for no longer than 1–2 hours), by dissolving 0·08 g of the Bis reagent in 80 ml of pyridine and then adding 400 ml of Mono reagent.

Acetate buffer. Dissolve 11·0 g of analytical reagent quality sodium acetate trihydrate in a little water, add 65 ml of analytical reagent quality glacial acetic acid and make to a volume of 500 ml with de-ionized water.

Method

Measure 80 ± 2 ml of sea-water sample, at a temperature between 18°C and 23°C into a 200 ml separating funnel, and add 1·0 ml of acetate buffer. Add 1·0 ml of chloramine-T solution, and wait for at least 90 seconds, although a period of up to 5 minutes does no harm. Add 40 ml of pyrazolone reagent and after at least 1 minute (5 minutes is still satisfactory) add 35 ± 0·5 ml of carbon tetrachloride from a dry 50 ml measuring cylinder. Extract the ammonia complex vigorously for at least one minute and allow the layers to separate. Run off the carbon tetrachloride layer through a small dry filter paper into a dry 10 cm spectrophotometer cell and measure the extinction against water at 4500 Å. The carbon tetrachloride extract is stable for at least 24 hours if evaporation is prevented.

Calculations

Sea-water salts reduce the extinction obtained from a given amount of ammonia. The extinction – salinity relationship is curved but between a salinity of 25‰ and 35‰ can be approximated to a straight line. The extinction obtained in pure water is some 1·6 times as great as the value obtained from the same amount of ammonia in water of a salinity of 30‰, much of the suppression occurring as the salinity increases from zero to about 15‰.

Each batch of samples should be corrected for a reagent blank by subtracting 0·62 times the extinction obtained from 80 ml of de-ionized water carried through the method at the same time as the samples. This blank extinction varies from batch to batch but is generally in the range 0·1 to 0·15 and appears to effect a satisfactory correction to each batch of samples. The final ammonia concentration may be calculated from the expression:

$$\mu\text{g at. ammonia N/l} = \frac{\text{corrected extinction} \times 8{\cdot}5}{(1 - 7{\cdot}6 \times 10^{-3} \times S)}$$

where S is the salinity in $^0/_{00}$.

Little error is incurred with samples having a salinity between $29^0/_{00}$ and $34{\cdot}5^0/_{00}$ by neglecting the salinity correction and using a factor obtained by calibration with $30^0/_{00}$ sea water, viz:

$$\mu\text{g at. ammonia N/l} = \text{corrected extinction} \times 11$$

Results

The method works very well in a shore-base laboratory, provided that the usual scrupulous precautions are taken against contamination, and has been used successfully at sea, working with batches of about 6 samples at a time (2 hours for complete analysis). The recovery of ammonium ion added to sea water is complete. The standard deviation of the method at a level of 5 μg at. N/l is about 0·2 μg at. and at 0·7 μg at. N/l is about 0·1 μg at. The limit of sure detection is around 0·1–0·2 μg at. N/l under normal routine working conditions. The surface coastal waters of the north-east Pacific in July 1958 had as much as 5 μg at. N/l of ammonia nitrogen present, but at a few metres depth the amount rarely exceeded 1–2 μg at. N/l. However, as much as 0·5–1 μg at. N/l was found at all depths down to 900 m, distributed in a somewhat erratic pattern. In this regard, the erratic results obtained by COOPER (1948a) should be borne in mind.

Notes on the Estimation of Reactive Iron

GOLDBERG, BAKER, and FOX (1952) pointed out the value of membrane filters of approximately 0·5 micron pore size in differentiating between "particulate" and "soluble" iron in sea water and LEWIS and GOLDBERG (1954) have described an excellent procedure for iron determinations using these membranes and α–α' dipyridyl for "particulate" and bathophenanthroline for "soluble" iron. For both analyses fuming perchloric acid was used to leach all forms of marine iron into true ionic solution. Recently ARMSTRONG (1957) recommended an autoclave technique using approximately 0·14 M hydrochloric acid to bring iron into solution. A less extreme form of attack was used earlier by COOPER (1948).

Although these methods, certainly the one described by LEWIS and GOLDBERG (1954), may bring about the dissolution of most forms of combined iron into a form reacting with 1:10 phenanthroline or similar reagents it is doubtful whether the results necessarily bear a close relationship to the amount of iron in sea water that is readily and immediately available to growing phytoplankton.

HARVEY (1937) and more recently GOLDBERG (1952) have produced evidence that the iron readily and rapidly available to growing phytoplankton is most probably in the form of small particles of hydroxide or phosphate. "Soluble" iron is available if present as colloidal hydroxide but is probably of little use if strongly complexed by organic material. It seems reasonable, therefore, to sort both "particulate" and "soluble" iron into biologically reactive and unreactive forms by treatment with a reagent that will rapidly dissolve all forms of precipitated or colloidal ferric hydroxide but leave untouched material such as

ignited iron oxides, ferric silicate compounds, unreactive clays and muds, etc. The problem is kinetic rather than a matter of thermodynamics. Treatment with hot hydrochloric acid of about 0·5 M concentration for 10–15 minutes dissolves all forms of precipitated ferric hydroxide and phosphate, even material dried to 110°C, but is practically without effect on less reactive ferric materials such as ignited iron oxides and clays and appears to have no marked leaching effect on the iron in plant tissues. The use of such a preliminary treatment is of great assistance, analytically, as no evaporation and fuming with strong acid is required.

We suggest treating a millipore HA filter, holding the "particulate" iron from a suitable volume of sea water, with 10 ml of a solution of 20·0 ml concentrated hydrochloric acid (s. g. 1·18) in 500 ml of water. The filter is digested in this extraction reagent by placing it at the bottom of a 50 ml stoppered measuring cylinder and heating the cylinder for 10 minutes in a boiling, or near boiling, water bath. After cooling the cylinder 2·0 ml of a sodium acetate buffer (75 g of trihydrate dissolved in 100 ml of water) are added and the determination may then be continued using α–α' dipyridyl as described by Lewis and Goldberg (1954) or others. Similarly for "soluble" iron, 100 ml of sample is allowed to stand with 10 ml of hydrochloric acid extraction reagent for about 15 minutes. After adding 2·0 ml of acetate buffer the determination may be continued as described by Lewis and Goldberg (1954), except that we have found that one extraction with 30 ml of iso-amyl alcohol is sufficient to remove iron from the aqueous layer. Full working details of the proposed method may be obtained from the *Standard Methods of Seawater Analysis*, Vol. 2, referred to earlier.

It would be useless to suggest that the above procedure is anything but arbitrary. However, it appears reasonable to assume that the amount of iron brought into solution by this method bears a more direct relation to the amount of immediate use to growing plant cells than does the total iron content of a sea-water sample. Results by the proposed method in north-east Pacific oceanic and coastal waters indicated that the total reactive iron rarely exceeded 0·3 μg at. Fe/l, even at the surface, and that generally half or more of this iron was "soluble". Methods measuring total iron generally give several times more "particulate" iron than "soluble" iron.

Notes on the Estimation of Nitrate

The copper catalyzed hydrazine reduction of nitrate to nitrite described by Mullin and Riley (1955) gives rise to an elegant and convenient method for the direct determination of nitrate in sea water. The procedure has shown great promise in our hands but two important factors affecting the method have come to light and may be worth reporting.

The extinction for a given concentration of nitrate is a function of the size and shape of the glass vessel used for the reduction. About 50 ml of sea water in a 125 ml Erlenmeyer flask gives a sensitivity that is nearly double that found when using the 50 ml volumetric flasks recommended in the original method. For both convenience and sensitivity, therefore, we favour the use of Erlenmeyer flasks but a drawback is that the resulting extinction is then affected by any motion of the flasks and is reduced by the rocking experienced during shipboard analyses. This may be overcome by using a small serological water

bath in gimbals and by processing standards with every batch of samples analysed. Reductions carried out in 50 ml volumetric flasks, filled to the neck, are not sensitive to motion.

Although the sensitivity of the method is not a function of temperature, over a reasonable temperature range, as stated by the authors, we have found that it is sensitive to *changes* in temperature during the first few hours of reduction. Flasks should be incubated with reductant in a thermostatically controlled water bath, the temperature of which does not change by more than $\pm$ 1°C throughout the first 4–6 hours of reduction. A *rise or fall* in temperature during this period can cause a drop in extinction of as much as 10–30%. Provided that the temperature is held constant it may be anywhere in the range of about 18°C–25°C without affecting the sensitivity.

Notes on the Estimation of Phosphate

Recently Murphy and Riley (1958) have proposed a single solution method for the determination of inorganic phosphorus in sea water. Samples are treated with a mixed molybdate – sulphuric acid – ascorbic acid mixture which gives rise to a procedure which is practically as sensitive as those using stannous chloride as reductant but which has none of the disadvantages of time and temperature dependence; repeated standardizations are unnecessary.

However the necessary reduction time is over 20 hours at room temperature or some 30–60 minutes at 50°C, as compared with the relatively few minutes at room temperature needed with stannous chloride. Such a lengthy reaction time in a solution which is about 0·25 M with respect to sulphuric acid might reasonably be supposed to effect the hydrolysis of organic phosphorous compounds in sea water. The authors did not find this to be the case, but we have to report that serious errors may result if the method is used in areas, such as British Columbia coastal waters, where the soluble organic phosphorus content of the water often exceeds the inorganic orthophosphate content. At Departure Bay (Vancouver Island) an analysis of the water at 5 m depth in June 1958 showed the inorganic phosphate to be 1·03 $\pm$ 0·05 μg at. P/l (stannous chloride), the soluble organic phosphorus to be 1·16 $\pm$ 0·11 μg at. P/l and the particulate phosphorus to be 0·92 $\pm$ 0·13 μg at. P/l. (The limits indicate an uncertainty range at the 0·05 probability level.) Simultaneous analysis by the Murphy-Riley method gave an apparent inorganic phosphorus value of 1·41 $\pm$ 0·07 μg at. P/l and it seems almost certain, therefore, that nearly a half of the soluble organic phosphorus compounds mineralized during the reduction.

Conditions here are probably extreme, and where the absence of organic phosphorus is ensured the ascorbic acid reduction technique has everything to recommend it. However, when a precise evaluation of the various forms of phosphorus is desired a reduction with stannous chloride still appears to be mandatory, despite the inconvenience, as a reduction in the shortest time at the lowest practicable temperature must be attempted.

Summary

The Kruse and Mellon extraction method for ammonia in sewage has been adapted for shipboard use in the analysis of sea water. Brief working details

are given. A method for the estimation of biologically reactive iron in sea water is suggested, based on the reactivity of marine iron compounds to dilute hydrochloric acid. Some notes are given on the use of the nitrate method of MULLINS and RILEY (1955) and on the "single solution" phosphate method of MURPHY and RILEY (1958).

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A Simple Apparatus for Routine Zooplankton Counts

By

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As part of an investigation on the ctenophore *Pleurobrachia pileus* (O. F. Müller), a simple apparatus was designed to facilitate the rapid handling of large numbers of this species for counting and examination of stomodeal contents under the low-power binocular microscope. The apparatus is shown in Figure 1, and involves the flow of a controllable current of water carrying the specimens through a suitably illuminated counting cell beneath the microscope objective.

Procedure

The whole system is first filled with sea water and the preserved plankton catch to be counted is introduced into bulb 4. A portion of it is then allowed to pass into the system by opening tap C and momentarily pressing spring-clip 11. Tap C is then closed and tap B opened, after which the organisms can be made to flow along in a current of water through counting cell 6 and to accumulate in container 9. From this container, the water passes on via funnel 10 and spring-clip 11 into reservoir 12. When the latter is full, reservoir 1 is empty and the two are simply interchanged, siphon branch 3 being used to eliminate any air bubbles which may have entered siphon 2 during the interchange. Speed of flow is controlled by manual pressure on spring-clip 11, and if any specimens should overshoot the field of vision of the microscope before being counted, they are brought back into view by releasing spring-clip 11 (i.e., stopping the flow) and pressing on rubber squeeze bulb 8. Both 11 and 8 are so placed as to be within easy reach of the observer's left hand, the right hand being used for focusing.

When the whole catch has been counted, portion by portion, and has thereby accumulated in container 9, the latter is detached, emptied, refilled with sea water, and refitted. Outflow 14 is used during this operation to eliminate any bubbles of air. Should a catch have to be left partly counted for any length of time, a little formalin can be run into container 9 from formalin reservoir 13 if desired.

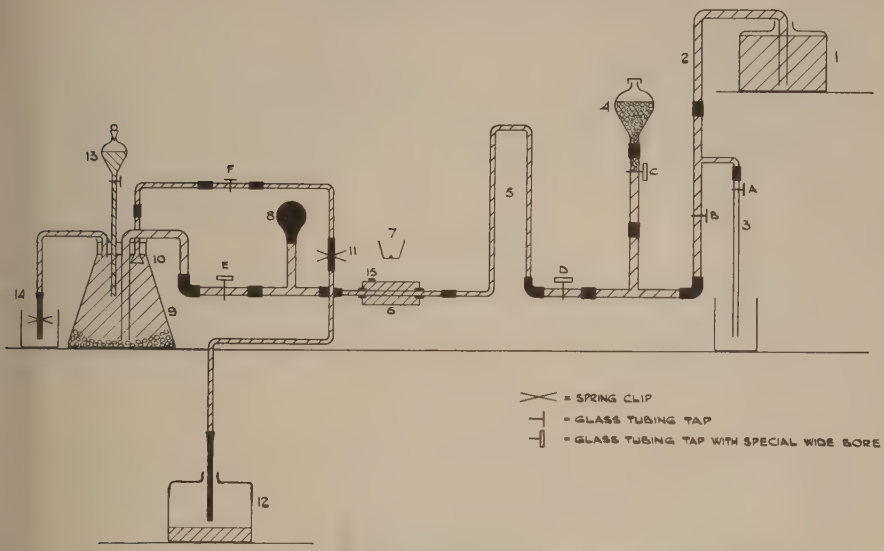

Figure 1. Counting apparatus for *Pleurobrachia pileus* and other common plankton organisms.
(1) Reservoir with sea water. (2) Siphon. (3) Siphon branch. (4) Bulb containing sample. (5) Loop of narrow glass tubing. (6) Perspex counting cell. (7) Objective of binocular microscope. (8) Rubber squeeze bulb. (9) Container receiving counted specimens. (10) Small gauze-covered funnel. (11) Control spring-clip. (12) Low reservoir for used sea water. (13) Formalin reservoir. (14) Alternative outflow from receiving container with spring-clip. (15) Stopper on counting cell.
Receiving container 9 considerably enlarged for clarity. Bench clamp stands supporting the apparatus, and microscope, omitted for clarity. Glass tubing taps labelled with letters. Taps C, D, and E with special wide bore.

All tubes and taps through which organisms have to pass are of wide bore to prevent blockage, with the exception of the tube in counting cell 6. This is as narrow as feasible to ensure that the organisms pass below the microscope objective in as nearly as possible single file. With *Pleurobrachia*, an additional length of such narrow tubing (loop 5) was found to be helpful for the same purpose.

Tap F is only closed when the apparatus is out of use for a period so that spring-clip 11 can be removed to preserve the rubber tubing.

Suitability for Zooplankton

Although the apparatus was designed and has largely been used for *Pleurobrachia*, it was also found very useful for counting *Calanus finmarchicus* (Gunnerus), various smaller copepods, and other common zooplankton forms which can be identified at sight and all of which travelled through the apparatus without difficulty. It is, however, obviously unsuitable in cases where manipulation of specimens or removal of appendages with needles is necessary for identi-

fication or other purposes and which consequently require an open counting tray or dish.

After a little practice, it was found possible to count the number, and record the stomodeal food content, of *Pleurobrachia pileus* at the rate of approximately 20 per minute. Details noted included number, presence or absence of food in stomodeum, the type of food organism if recognizable, e.g., "amphipod", "*Evadne*", etc., and whether there were few or many food organisms present.

Acknowledgement

The apparatus described was made and used whilst I was on the staff of the Dove Marine Laboratory at Cullercoats, and I am much indebted to Dr. H. O. Bull, Assistant Director of the Laboratory, for his help and advice in connexion with it.

Summary

A simple apparatus to facilitate routine counts of large numbers of *Pleurobrachia pileus*, common Copepoda, and other easily identifiable zooplanktonic forms is described, together with its practical operation. It involves the flow of a controllable current of water carrying the preserved organisms through a suitably illuminated counting cell beneath the microscope objective.

The Seasonal Variation in Oceanic Production as a Problem in Population Dynamics

By

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Introduction

The quantity of oceanic production is probably dependent in some way on the quantity of available nutrient and so the low quantities of phosphorus in the Tropics are taken to indicate low levels of production. This view of oceanic production is the chemical one which has given minimal and consistent results in such well studied areas as the English Channel and the Atlantic coast of the United States.

The view of production presented in this paper is a biological one based primarily on the conflict of populations. Certain simplifications are made, treating the whole algal community as a prey and the whole herbivore community of zooplankton as a predator. This is justified on the grounds that although many algal species and many species of zooplankton are mixed together, there is no emigration or immigration except on a minute scale and that the algae reproduce in the common sunlight and are probably eaten in almost a random manner in the mixing waters.

There are three sections to this paper, firstly a short description of a model of plankton production[1]), secondly a discussion of production as a predator/prey process, and lastly a description of seasonal differences as functions of this process.

I. A Model of Plankton Production in the Central North Sea

It was assumed that there was only one algal species and that the individuals were of constant size (10,000 μ^3). Specific differences and size differences were neglected because it was thought that they were less marked for the present purpose than differences in reproductive rate. The herbivorous zooplankton

[1]) A fuller description will appear in CUSHING, D. H. (in press) "On the nature of production in the sea". Fish. Invest., Lond., Ser. 2, **22** (6).

were placed in two groups, *Calanus* and "*other copepods*": individuals of the former group are about ten times bigger than those of the latter.

For the purposes of the present model, the predator/prey process may be stated formally as follows: —

$$\frac{dP}{dt} = (R\text{–}G)\,P \tag{1}$$

$$\frac{dH}{dt} = (R_H\text{–}M_H)\,H \tag{2}$$

where P is the number of algae per unit volume or beneath unit surface,
where H is the number of herbivores per unit volume or beneath unit surface,
where R is the daily algal reproductive rate,
where G is the daily rate of grazing mortality on the algae, combined for both herbivore groups,
where R_H is the daily reproductive rate of either group of herbivore,
where M_H is the daily mortality rate of either group of herbivore.

The second equation is operated separately for *Calanus* and for other copepods. The parameters of the two equations are related as follows: —

$$G = f(H) \tag{3}$$

$$R_H = f(P) \tag{4}$$

The operation of the model is a little complicated for three reasons. The first is that the algal reproductive rate is dependent upon the interplay of two physical factors as spring progresses in the sea, the increase of radiant energy and the decrease of vertical turbulence. The second complication is that the relation between the grazing mortality coefficient and the number of herbivores is not a simple one, nor is that between the herbivore reproductive rate and the number of algae. The third point is that as a copepod lives for about 8–12 weeks, there are rapid size changes causing quick changes in reproductive capacity and in grazing capacity; consequently, the herbivore population is most readily dealt with in stages.

In the depth of winter in temperate seas, there is no increase in either the algal or herbivore populations. When winds are high and the sun is low in the sky in the wintertime, the algae are not allowed to remain long enough in the shallow photic layer to do more than respire. Consequently, no reproduction can take place. The numbers of herbivores are very small and the effect of grazing is also very small and so the algal populations remain virtually constant. This level of algal numbers is well below the threshold for herbivore egg production and so the herbivores cannot reproduce and if mortality is low, their populations must also remain constant.

In spring, the total quantity of photosynthesis is proportional to the daily income of radiant energy, whereas the total quantity of respiration is constant. So production can only start when the total photosynthesis in a day exceeds the total respiration. In the sea in winter, the mixed layer is much deeper than the photic layer and so the algae only spend part of the day in the light; production can only start when the mixed layer has become shallow enough to allow the total photosynthesis in the mixed column to exceed the total respiration (SVERDRUP, 1953).

The algal reproductive rate was estimated in the following way. LUND (1950) has published data on the division rates of *Asterionella formosa* Hass, a diatom, in Windermere at 5 m and at 7 m, with contemporaneous measurements of light ashore in kiloluxes. SVERDRUP, JOHNSON, and FLEMING (1942) give factors for converting lux to energy, and the surface energy received to that used in photosynthesis. Thus, it was possible to relate division rates to energy. This relation was used in the central North Sea with JERLOV's (1951) classification of water types; so differences in the spectral composition of light between Windermere and the North Sea were adjusted. The daily income of energy, taken from SVERDRUP *et al.* (1942) corrected for length of day and the sun's altitude and the appropriate energy extinction coefficients, was used to estimate a daily algal division rate.

The depth of the mixed layer was derived from average measures of wind speed (Service Hydrographique, ICES 1950–53) in the central North Sea using EKMAN's formula for the depth of frictional resistance (SVERDRUP *et al.*, 1942); then the depth of the photic layer was expressed as a fraction of the mixed layer. The estimated algal reproductive rates were reduced by this fraction, which expresses the effect of the wind. Thus, the algal reproductive rates were estimated only from weekly measures of sunlight and of wind strength.

The grazing rate of the herbivores was based on the assumption that copepods find their algal food by encounter and that the battery of sensory hairs along the antennules are tactile appendages. The transverse cross section of the animal including all appendages, called the "contact surface", was measured. Some estimates of minimum distance travelled in a day were available from the literature on the vertical migration of plankton. This distance multiplied by the "contact surface" gives a mechanical "volume swept clear" per day (*Sm*). A copepod can only eat one diatom at a time and so when diatoms are dense, this "mechanical" volume swept clear is reduced in proportion to the sizes and numbers of algal cells in the following way: —

$$1 - p = p.v.x.y$$

$$\text{i.e., } S_o = \frac{S_m}{1 + v.x.y}$$

where S_o is the operational "volume swept clear" $= p.\ S_m$,
where x is the time to eat one algal cell in seconds,
where v is S_m sec.,
where y is the number of algae/ml.

Then $G = S_o.H$ in ml swept clear/1000 ml, H being the number of herbivores per litre. It is possible to add the grazing effects of both herbivore populations to obtain a combined daily grazing mortality coefficient for use in the algal equation. Thus, although the two herbivore populations are operated separately, their grazing effect is combined in the algal equation.

The herbivore reproduction rate is based on some experiments of MARSHALL and ORR (1952), showing that egg production of copepods increases with algal numbers; it is not a linear relation, but an asymptotic one, starting at a fairly high threshold value. The mortality of nauplii and younger copepodites was estimated from the detailed studies by NICHOLLS (1933) in Loch Striven.

There is no need to describe the working of the model in further detail. It does fit the few field observations fairly well. The peak quantity of algae in

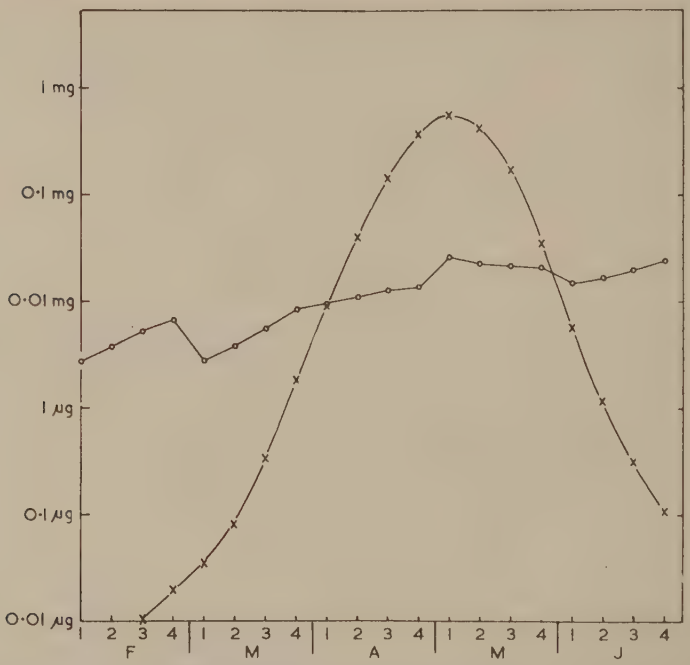

Figure 1. Theoretical algal production (×—×) in wet wt./litre/week in the central North Sea from February to June. The herbivore production (o — o) in wet wt./litre/week for the same period is also shown.

the central North Sea is about 0·5 mm^3/l at the end of April or the beginning of May; subsequently, the numbers decrease very rapidly. The numbers of *Calanus* increase from 0·01/l to about 0·4–0·5/l in May and the "other copepods" from 0·1/l to 4–5/l in June. Figure 1 shows that the model runs efficiently within these limits. Because of the large number of variables used, this is not necessarily an adequate test. It becomes more adequate when it is realized that the theoretical values of the reproductive rate were close to those observed at sea in 1949; also that over the season of the spring outburst, the herbivores get enough to eat and the total herbivore production amounts to about one-seventh of the total algal production.

II. The Model as a Predator/Prey Process

As in the classical predator/prey studies (LOTKA, 1925; VOLTERRA, 1928), the parameters of the two equations are interdependent. There are, however, certain differences between this model and the classical ones. The first is that the parameter which drives the whole system, the algal division rate, is dependent upon two physical factors, radiant energy and vertical turbulence, the sun and the wind. The second difference is that the parameters linking the two equations are not linearly related. As algal numbers increase, the total mortality

coefficient due to herbivore grazing decreases. So the grazing mortality rate on the algae depends inversely upon the numbers of algae and directly upon the numbers of herbivores. Herbivore egg production is dependent upon algal numbers, and upon herbivore numbers, the algal function being asymptotic in egg production.

There are two further differences associated with the herbivore populations. The first is that there is a threshold in the relation between egg production and algal numbers (at $10^6/\mu^3/l$). Consequently production of herbivores cannot start until eggs are produced at the threshold level of algal numbers. The second difference is that it takes perhaps three weeks for the herbivore egg to develop into a copepodite of significant grazing capacity. The two factors, the threshold to egg production and the development of the copepodite give rise to two delay periods, which are added. This combined factor is analogous to the delayed density dependent effects described for predators by VARLEY (1947).

During this delay period, which may be as much as three weeks, the daily algal division rates rise from 0·1 to 0·5. Consequently the algal numbers increase during the spring outburst by one hundred to one thousand times or more. The control of algal numbers can only take place after the end of the delay period, when the first generation of herbivores increases in size and grazing capacity and so the grazing rate on the algae tends to equal the reproductive rate of the algae. Thus, the algal reproductive rate may be said to drive the productive system and algal populations are controlled by the grazing of the herbivores.

It has been shown by me experimentally that *Temora longicornis* Boeck, a copepod, will eat up to ten times its immediate metabolic needs, if given the chance, in a large vessel (CUSHING, 1958). There are two interesting consequences of this observation. The first is that there is a high rate of nutrient regeneration, which is immediate; and in the sea, I have observed that *Calanus finmarchicus* (Gunn.) in April will excrete into the water much more phosphorus than might be expected from the carbon/phosphorus ratio in copepod flesh. The second consequence is that there is a large production of particulate excreta, which may provide a partial basis for feeding in the less productive season of high summer.

If immediate nutrient regeneration is important then the uptake of nutrients must be balanced to some extent by their regeneration as production proceeds. If uptake were proportional to production and regeneration to the quantity grazed, then there would be a rough balance between the two until about the time of peak algal numbers. The quantity produced is maximal just before that time and the quantity grazed is maximal a little later, because the standing stock is then being rapidly eaten up. So the greatest increment to herbivore material is added just after the time of peak algal numbers; in Windermere, the quantity of silica locked in particulate excreta and living material at this time was one-third of the total silica budget for the year. This large fraction of nutrient lost to the productive system coincides with the peak of algal numbers, because both are functions of the increased grazing capacity, which at this time yields the greatest quantity grazed and also controls the algal numbers. These relations are set out diagrammatically in Figure 2.

If this argument is true, then the decline of nutrients in spring and early summer does not limit the production in the spring outburst, although the consequent lack of nutrients might well restrict it later. The decline in nutrients

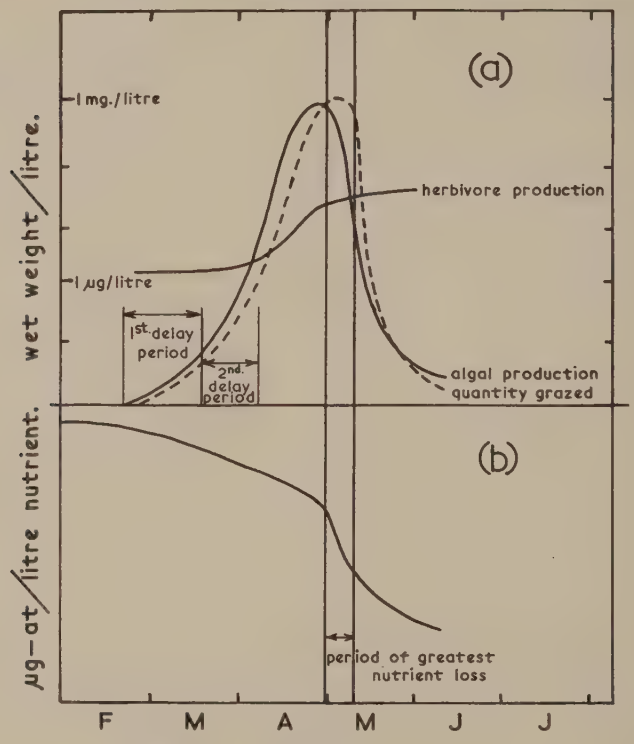

Figure 2. Algal production and nutrient loss.
(a) Weight of algae produced and weight of algae eaten from February to June. Weight of herbivores produced from February to June.
(b) The reduction in the quantity of nutrients from February to June.

might be described as a symptom of production and in the case of phosphorus and nitrogen, it would be exactly related to the increase in the herbivore population rather than to the rapid changes of the transitory phytoplankton.

Summarizing, the spring outburst of production in temperate seas may be visualized as a predator/prey system, which proceeds in an unbalanced manner because of the delay period to the grazing capacity. The consequence of the delay is firstly, the unfettered algal outburst, secondly the excessive herbivore grazing and thirdly, as a consequence, the decline in nutrients.

III. The Seasonal Cycle of Production in Different Regions

In temperate and arctic waters there is no production in winter because the photic layer is only a small proportion of the mixed layer. But, production in the Sargasso Sea and in the Mediterranean continues throughout the winter; in fact, BERNARD (1939) and RILEY, STOMMEL, and BUMPUS (1949) have shown

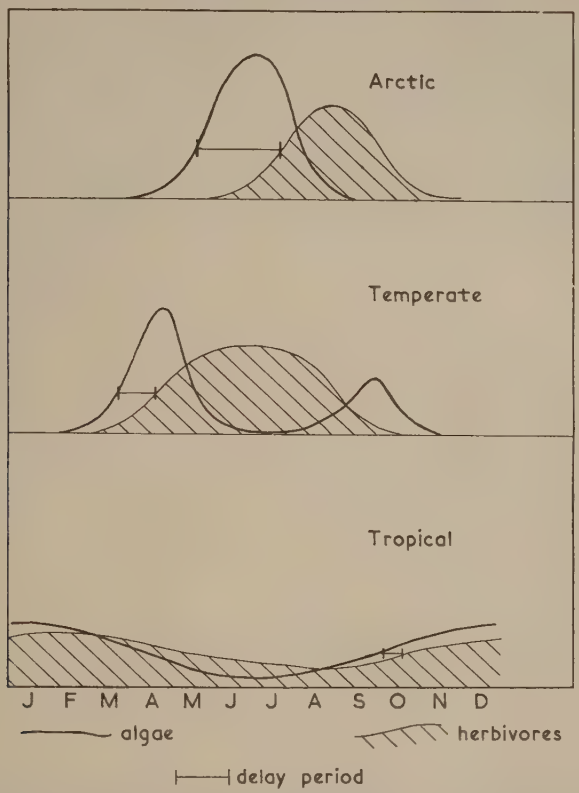

Figure 3. Diagram representing the seasonal amplitudes in algal and herbivore production in different latitudes.

that the highest algal numbers are found there in December. The seasonal range of algal numbers is least in the Tropics where production is continuous and most in high latitudes where production is limited to a short season.

The three main patterns of seasonal production are shown in Figure 3, tropical, temperate, and arctic (or antarctic). In the Arctic the daily radiation increases from zero in March to a maximum in June, with a 24 hour day, and the range in reproductive rate is greatest in the Arctic. The delay period in reaching the threshold in food for egg production is long, because the rate of change of radiation is slow at first; the delay period is further extended by the slow development of herbivores in cold water. Towards the end of the extended delay period, the algal reproductive rate will be higher than elsewhere because the daylight is continuous and very high relative to that at the beginning of the delay period; this factor combined with the long delay periods gives the algal standing stock the greatest chance to be very large and in high latitudes it may not be controlled by grazing. The algae reach maximum numbers at

midsummer, with a single long-lived brood of herbivores following in late summer and in early autumn. The delay period in the Arctic is the longest of all and as a consequence the productive system is the most unbalanced.

In temperate waters, the productive cycle starts earlier. The range in the daily algal reproductive rate will necessarily be less, the herbivores will develop more quickly in the somewhat warmer water (6°–10°C, as opposed to 0°–3°C in the Arctic) and so the delay period will be relatively shorter than that in the Arctic. In fact, it is short enough to allow the algal populations to be certainly controlled by grazing. The herbivore population builds up to midsummer and when it declines again in early autumn, a secondary algal outburst sometimes takes place.

In the Tropics the delay period is small and so the increase in algal reproductive rate during the delay is also small and the algal production takes place early enough in the year for it to be described as a winter outburst. In temperate and arctic waters, the seasonal amplitude in algal numbers may reach a thousand times, but in tropical waters it may be as little as five times. In other words, in the Tropics, production is a continuous or even a steady state process, in which the algal reproductive rate is always more or less balanced by or equal to the grazing rate of the herbivores. There is a narrow seasonal range in reproductive rate, the shortest of delay periods and, in this low but continuous cycle, there is very little seasonal variation in nutrient content.

Considering the whole range of regional variation, the most important single physical factor is the lack of sufficient winter sunlight away from the equator. The indirect effect of this on the predator/prey process is to introduce a delay period, which increases with latitude; also, the longer the delay period is, the more unbalanced do the productive cycles become. On a flat earth with no seasons, oceanic production could well be in a true steady state, in which the algal reproductive rate and the herbivore grazing rate were approximately equal all the time. In the high latitudes of our round earth, the two parameters, however, can be so different that enormous algal populations are produced.

Our present ideas of the productive capacity of the tropical oceans are usually related to the areas of upwelling. For example, in the Benguela Current and in the Peru Current, cold nutrient-rich water is brought up to the surface and, in these regions, dense algal populations are found. The seasonal picture, as described above, is completely changed because the productive season depends upon the season of upwelling. The upwelling water is cold and turbulent and must contain a low plankton population; the algal reproductive rate would necessarily be slow until the turbulence were reduced and it is likely that there would therefore be some sort of delay period in the system and algal production could increase greatly during that delay period. Hence, an unbalanced system would be set up, yielding high algal numbers and, in the Peru Current at least, a guano industry. Thus, it might well be that the areas of high algal numbers were also effects of a delay period as in higher latitudes; then, the presence of large quantities of nutrients in such areas, is, if not quite irrelevant, perhaps merely fortuitous.

In the extremes there are two entirely opposed types of productive cycle, tropical and arctic. The tropical cycle is of low amplitude, is continuous and is characterized by constant low nutrients and low peak algal standing stock; the arctic cycle is unbalanced, discontinuous and is characterized by a nutrient cycle and a very high peak algal standing stock. The predator/prey process

described here is only part of the productive cycle and an exact comparison of tropical and arctic production is not yet possible because the higher tropic levels cannot yet be adequately sampled. However, within the primary predator/prey process, it is likely that the tropical cycle is more efficient merely because the longer the delay period the greater the chance of the algae dying in other ways than by grazing. This is perhaps why the diatomaceous ooze is found on the floor of the Southern Ocean. It may be said that the primary predator/prey process comprises the greatest part of the productive cycle; consequently, there is some reason to believe that tropical oceans are less barren than considered hitherto.

Summary

A model of plankton production in temperate seas is described. The algal community is treated as a single prey and the zooplankton community as two predators, *Calanus* and "other copepods". Algal division rates are derived from average measures of radiant energy and wind strength. The coefficient of grazing mortality of algae is derived from an encounter theory of grazing, by means of which *Calanus* "sweeps clear" 1–3 l/day. The herbivore reproductive rate as number of eggs/day is dependent upon the quantity of food available, from a threshold upwards.

Considered only as a predator/prey process, there is a delay period to the grazing capacity of the herbivores. Eggs cannot be produced until a threshold in algal food is reached and then the egg takes perhaps three weeks to develop into a copepodite of significant grazing capacity. During this delay period algal numbers increase by one hundred to one thousand times. This outburst is controlled in the model by herbivore grazing.

To achieve this, grazing is five to ten times in excess of the animals' immediate needs, which may also be shown in the immediate regeneration of phosphorus. It is suggested that the decline of nutrients in the spring takes place just after the algal outburst. Any nutrient observation strikes a balance between uptake and regeneration; the peak of the algal outburst is the peak of production and most nutrient is then being transferred to herbivore flesh. So the gap between uptake and regeneration is then greatest and the nutrient content falls.

It was suggested that seasonal patterns of production differ mainly in the length of the delay period, which increases with latitude. The production in upwelling regions was fitted into the same scheme.

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Separation of the Sexes of *Calanus finmarchicus* (Gunn.) in the Fifth Copepodite Stage, with Comments on the Sex Ratio and the Duration in this Stage

By

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A considerable body of data has been published on the variations in the size of *Calanus finmarchicus* (Gunn.) in its different developmental stages. In a number of instances measurements of the fourth and fifth copepodite stages have shown a bimodal distribution which has been attributed by authors to the presence of individuals which have developed at different temperatures, or under different feeding conditions, or to the presence of two "races" in the plankton samples. Studying the biometry of *C. finmarchicus*, BARNES and BARNES (1953) found that in the fifth copepodite stage many of the measurements still separated quite clearly into two size groups in a sample which was derived largely from a single generation in the Firth of Clyde. In particular they found that in one group of fifth stage copepodites the head was longer and the metasome narrower than in the other group; they related the first group to adult males and the second group to adult females. Whilst their results suggest that sexual differentiation takes place prior to the adult stage in *C. finmarchicus*, BARNES and BARNES emphasize that the differences are population differences in regard to measurements and cannot be used to separate individuals. WOODHEAD and RILEY (1957) have demonstrated similar population differences in measurements made on *C. helgolandicus* both in the English Channel and in the North Sea, and have used these measurements to confirm a method for separating the sexes of *C. helgolandicus* in Stage V by examination of the urosome. The present paper describes a similar method for the separation of the sexes in Stage V of *C. finmarchicus*, and then applies the method to determine the sex ratio in this stage, and to achieve an estimate of the duration of the fifth copepodite stage in the North Sea.

Method of Separation of the Sexes in Stage V

The material used consisted of fifth stage copepodites of *Calanus finmarchicus* (in the sense of REES, 1949) from the centre of a patch of *Calanus* in the North Sea off the north-eastern English coast in May, 1954. The *Calanus* were taken with a vertically hauled Hensen net and preserved in 5% neutral formalin as soon as possible after collection.

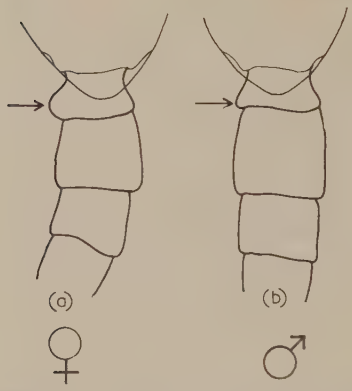

Figure 1. Urosome of Stage V potential female (a), and male (b) types. Arrows indicate ventral bulge on the proximal segments.

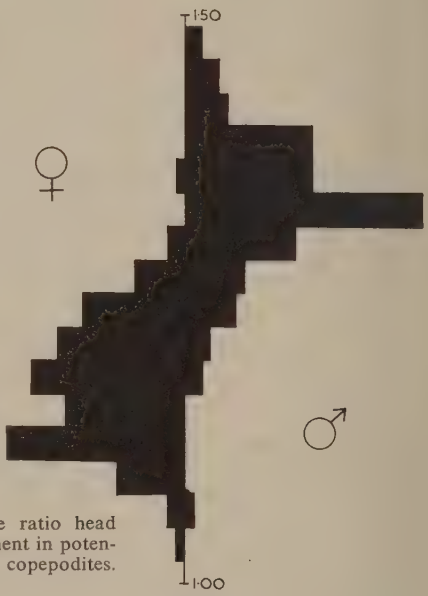

Figure 2. Frequency distribution of the ratio head length/width of first free metasomal segment in potential female and male types of Stage V copepodites.

Figure 2.

Examination of the first (proximal) segment of the urosome of these fifth stage copepodites showed that two types could be separated, as had been previously reported for *C. helgolandicus* (Woodhead and Riley, 1957). In one type the distal ventral edge of the proximal segment formed a simple lip which was slightly curved to overlap the second segment. The second type was characterized by a more pronounced curvature of the ventral surface of the segment, the curve extending further forward and tending to bulge the segment out ventrally (Fig. 1). It was thought that the first type might represent the potential males, and the second, the potential females in this stage. In both sexes the ventral surface of the proximal segment of the urosome was found to be less curved than in the respective sex of *C. helgolandicus*, and the two types were, in fact, rather easier to distinguish in *C. finmarchicus*.

Measurements of the head length, and the width of the first free metasomal segment of the Stage V copepodites showed that two size populations existed within this North Sea sample, similar to those found for the Firth of Clyde (Barnes and Barnes, 1953). These measurements were then used to confirm the sex separation in *C. finmarchicus*, as had previously been done for *C. helgolandicus*. The Stage V's were separated into two groups on the urosome feature and then measured under a dissecting microscope. It was found that the copepodites selected as potential females by the urosome feature tended to have shorter heads and longer bodies than the copepodites in the potential male group. A maximal separation of the two groups was achieved by dividing the head length by the width of the first free metasomal segment, which also eliminated variations due

to differences in the size of the copepodites. When the ratios were derived it was found that an approach to a normal distribution was achieved for each population selected on the urosome feature (Fig. 2).

Both the urosome and biometrical methods select the copepodites on features which approximate to the adult male and female conditions and the close agreement between these methods suggests strongly that the two types in Stage V are the potential males and females respectively. But neither method offers conclusive proof of the sex of a copepodite, however; in a number of the older Stage V females the ovary can be seen through the body wall; this was used to check the separation and it was found that in all cases where a developing ovary could be seen, the Stage V copepodite had a "female" type urosome.

The Sex Ratio in the Fifth Copepodite Stage

Numerous investigations have shown that the proportion of adult male to female *C. finmarchicus* caught at sea is usually low, although the ratio varies with both time and place. Similar scarcities of adult males have been reported for other copepods (e.g., MARSHALL, 1949), but it is generally accepted that this is due to the shorter adult life of the male (RUUD, 1929; REES, 1949; MARSHALL and ORR, 1955). For *C. finmarchicus* this is supported by the work of RAYMONT and GROSS (1942) who found that whereas adult males died in one or two weeks when kept in laboratory cultures, adult females lived for three to nine weeks under the same conditions. Similar results have been reported by MARSHALL and ORR (1955).

Since it has not previously been possible to distinguish the sexes in *C. finmarchicus* before they were adult, little is known of their relative numbers in the copepodite stages. However, MARSHALL and ORR infer that the sexes may be about equal since MARSHALL (1949) found them to be approximately equal in the fourth and fifth copepodite stages of other species in which the males were generally scarce as adults. Also BARNES and BARNES (1953) found that the two size populations, which they suggested represented potential males and females in fifth stage *C. finmarchicus*, each formed about fifty per cent. of the sample.

Occasionally collections of adult *Calanus* have been made in which males considerably outnumber the females. These collections have nearly always been taken when a number of adults are beginning to moult from Stage V (FARRAN, 1929, S. Ireland; NICHOLLS, 1933, Clyde; ØSTVEDT, 1953, Norwegian Sea; USSING, 1938, Greenland), and when a series of collections have been made over a sufficiently short period it is apparent that the males tend to appear before the females, indicating a shorter development time for the males, in addition to their shorter adult life.

Since males precede the females from Stage V it would be expected that the percentage composition of the sexes in the fifth stage would not be constant at 50:50 but would vary, the proportion of females increasing as the males become adult. Plankton collected by Dr. D. H. CUSHING (work in preparation for publication) on a series of Hensen net surveys off the north-eastern English coast in 1954 provided material to investigate whether the predicted change in sex ratio really occurred. On these surveys a repeated grid of plankton hauls had been carried out following the movement of plankton patches and sampling

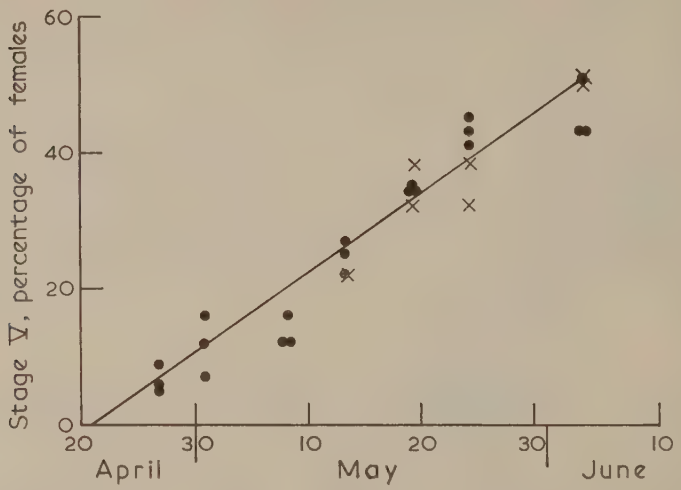

Figure 3. Change in the ratio ♀ : ♂ with time in the patch of Stage V copepodites.
● = *Calanus finmarchicus*
× = *Calanus helgolandicus*

the patches at fairly short time intervals. From this material a patch of fifth stage copepodites was chosen which had been sampled several times in succession after its first appearance from Stage IV. Three samples were chosen from stations near the centre of the patch on each occasion that it had been sampled; from each sample one hundred fifth stage copepodites were examined and the percentage of each sex present, as selected by the urosome feature, was recorded. The results are presented graphically in Figure 3.

It can be seen that at any one time there was fairly close similarity in the proportion of the sexes found at the three stations. The results show an increasing percentage of females with time, as was expected; however, the change in the proportion of the sexes did not begin at 50% but with more than 90% potential males.

These results suggest that the males develop more rapidly than the females in the fourth stage as well as the fifth stage. Therefore, the males appear first in Stage V; the percentage of females subsequently rises as they enter this stage from Stage IV, and also because the males are passing out of Stage V to become adult before the females. As the proportion of the two sexes is constantly changing it has not been possible to determine the absolute sex ratio in Stage V.

Throughout the investigation the copepods were checked by examination of the fifth pair of thoracic legs to ensure that no *C. helgolandicus* were included (Rees, 1949). In this way it was found that the plankton samples included a small percentage of *C. helgolandicus* and for comparison the sex ratio in Stage V of this form was determined at a few stations (Fig. 3). It is interesting that although Rees (1949) described *C. finmarchicus* and *C. helgolandicus* as having separate life cycles in the North Sea, on this occasion the sex ratios in *C. helgolandicus* Stage V's appeared to be changing in the same way and at the same time as that of *C. finmarchicus* in the seven samples examined.

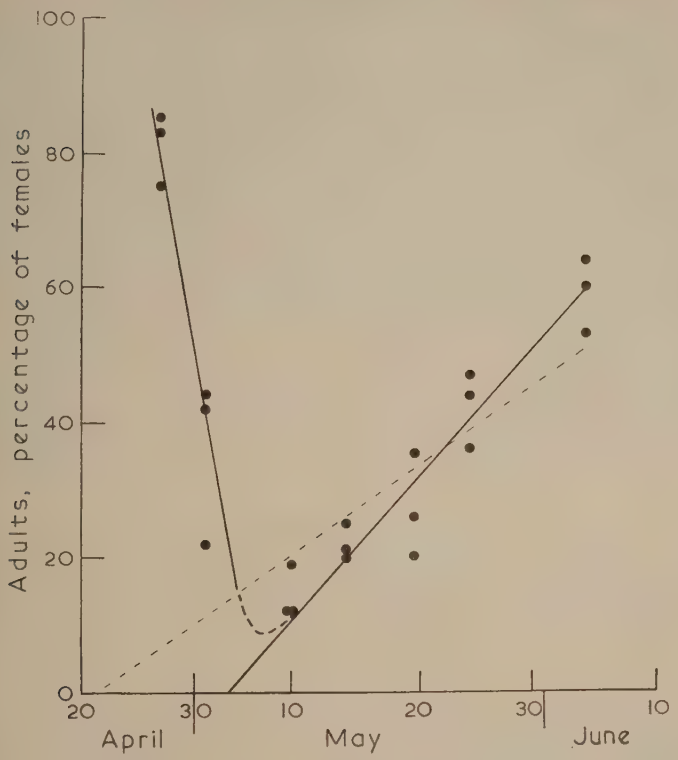

Figure 4. Change in the ratio ♀ : ♂ with time in the adult copepods at stations for the Stage V's shown in Figure 3.
—— = line for the change in ratio of the adults,
------ = line for the change in ratio of the Stage V's.

Separation of the Sexes in Stage IV

Since the males tended to moult from Stage IV before the females it was possible that some degree of sexual differentiation might be discernible in this stage. An attempt was therefore made to separate the potential sexes in the fourth stage copepodite of *C. finmarchicus*. This was done by measuring these copepodites and then deriving the ratio of the head length to the width of first free metasomal segment; in all, some 700 copepodites from several stations were measured. However, the frequency distribution of the ratios generally showed only one population of measurements and no significant trend could be seen.

Duration of the Fifth Copepodite Stage

The determination of the sex ratio of adult *Calanus* on the same stations that had been used for the Stage V's showed that initially nearly all the adults were

female, but these females only occurred in small numbers, being the last survivors of the previous generation. The first adult copepods of the new generation to appear were the males which rapidly outnumbered the last of the older females, so that the percentage of females fell to a low figure. This percentage later increased as the females of the new generation moulted from Stage V to become adult (Fig. 4). Although there is rather more variation in the sex ratio of the adults than was the case for the Stage V's, the change in the sex ratio with time appears to be best expressed by a straight line. Comparing this line with that for the Stage V's, it is clear that the slope for the adult line is much steeper, indicating a more rapid accumulation of females, probably due to the shorter life of the adult male (Raymont and Gross, 1942).

Extrapolation of the lines expressing the temporal change in sex ratio of the adults and the Stage V's, gives an approximate estimate of the dates of first appearance of the females in these stages, and if it is accepted that the first females to appear in Stage V would also be the first to become adult, the difference between these dates of 12 days gives an approximate estimate of the duration of the females in Stage V. Since the males develop more rapidly than the females, the duration of the potential males in Stage V would be less than 12 days.

Acknowledgement

We wish to record our gratitude to Dr. D. H. Cushing for allowing us to use his plankton collection, and for access to his unpublished data on the distribution of *Calanus* off the NE coast in 1954.

Summary

1. A method has been described for the separation of the sexes in the fifth stage copepodite of *C. finmarchicus* by examination of the urosome. The method was supported by evidence derived from the biometry of this stage.

2. The proportion of the sexes in a patch of Stage V copepodites in the North Sea was followed over six weeks. Initially almost all the Stage V's were males, suggesting that the males developed more rapidly than the females in Stage IV. The percentage of males in the patch decreased with time. Similar changes occurred in Stage V *C. helgolandicus* in this patch.

3. It was not possible to separate the sexes in the fourth stage copepodites of *C. finmarchicus*.

4. The duration of the potential females in Stage V was estimated as about 12 days in this generation in the North Sea; the duration of the potential males in Stage V is probably rather shorter.

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Observations on the Swimming Speeds of Fish

By

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Introduction

Most of the published work on the swimming speeds of fish has been reviewed by BAINBRIDGE (1958). Much of it is concerned with freshwater species and apart from the work of MAGNAN (1930) there are few data for marine species of commercial importance.

These swimming speeds have been measured in a number of ways, the principal ones being: —

1. Timing the movements of fish in tanks, culverts, fish passes, or from ships at sea.
2. Measuring the speed of lines running out after hooking fish.
3. Cine-photography of fish in aquaria.
4. Measuring the speed of rotation of annular-shaped tanks in which fish are kept stationary relative to the ground.

For instance, MAGNAN (1930) used methods 1, 2, and 3 on a wide variety of species. GERO (1952) used method 2 on very large barracuda and sharks, GRAY (1953, 1957) used method 3 on a number of freshwater species, and BAINBRIDGE (1958) method 4 on three freshwater species.

A programme of work designed to measure the swimming speeds of some marine species exploited commercially was started at the Marine Laboratory, Aberdeen, in 1955. It was considered that such data would prove useful in the design and assessment of fishing gear as well as in the interpretation of fish behaviour. Preliminary accounts were presented in 1957 to the Society for Experimental Biology when consideration was given to the relation between swimming speed and length, and in 1958 to the Challenger Society when an attempt was made to relate swimming speed to the avoidance of nets. It is hoped to publish details of these aspects when further work has been completed. Meanwhile, in view of the present interest in this subject, it seemed useful to present here some of the basic data which have been accumulated so far.

Materials

The work has been concerned principally with the following species: —

Herring (*Clupea harengus*), Cod (*Gadus callarias*), Haddock (*G. aeglefinus*), Saithe (*G. virens*), Whiting (*G. merlangus*), and Sea trout (*Salmo trutta*).

In addition, a considerable amount of data has been obtained for: —

Brown trout (*Salmo trutta*), Goldfish (*Carassius auratus*), Mackerel (*Scomber scombrus*), Plaice (*Pleuronectes platessa*), and a few observations have been made on: Blenny (*Zoarces viviparus*), Butterfish (*Pholis gunnelus*), Dab (*Pleuronectes limanda*), Eel (*Anguilla vulgaris*), Flounder (*Pleuronectes flesus*), Goby (*Gobius minutus*), Gurnard (*Trigla* spp.), Lemon Sole (*Pleuronectes microcephalus*), Stickleback (*Gasterosteus spinachia*), and Sprat (*Clupea sprattus*).

Difficulty was experienced in getting fish of the requisite wide variety of sizes and maintaining them in the aquarium. It is unlikely that swimming speed data for the whole size range of any species can be obtained without considerable effort expended in catching the fish when small, and allowing them to grow in captivity. It may be necessary to rear the earlier stages in tanks.

For these reasons data over wide size ranges have not been obtained for all species. The most complete data are available for herring and cod. A wide size range of herring was obtained by hatching and rearing the larvae in the aquarium, by capture of 0-group and I-group herring using a beach seine in the River Dee and by catching larger fish in drift-nets and transporting them to the laboratory.

It is necessary to catch most roundfish in shallow water using short trawl hauls but this limits the size range, the larger fish being in deeper water. However, large cod could be caught fairly easily by line in the neighbourhood of Aberdeen. Mackerel of a limited size range were also caught by line in Aberdeen Bay.

Flatfish and littoral species were obtained by trawl in shallow water. Sea trout were caught by beach seine in the River Dee and brown trout were transported by van from the Freshwater Fisheries Laboratory at Pitlochry.

Methods

Swimming speeds have been measured in these experiments in the following ways: —

1. By placing fish in tubes through which a current of water is being passed. Four different sized tubes were used: one made of glass 2·5 cm in diameter and 60 cm long, two of perspex, one 5·0 cm and the other 7·5 cm in diameter and both 120 cm long, and the fourth made of galvanized iron 30 cm in diameter and 150 cm long. The first three tubes were fitted with screens at either end and a hatch for inserting or removing the fish. Water was pumped from a reservoir through the tube and returned to the reservoir. By-passes were fitted to take any excess flow. A small centrifugal pump operated by a 0·25 h.p. electric motor was used to pump water through the 2·5 cm tube, the flow being controlled by a rheostat. A maximum water velocity of about 150 cm/sec. (5 ft/sec.) could be produced. A 5·0 cm centrifugal pump operated by a 2·5 h.p. petrol engine was used to pump water through the 5·0 cm and 7·5 cm perspex tubes, the maximum water velocities obtainable being about 430 cm/sec. (14 ft/sec.)

and 185 cm/sec. (6 ft/sec.) respectively, the flow being controlled by a calibrated stop cock. The velocity of water flow was determined by measuring the speed of air bubbles passing along the tube, the results being checked by measuring the quantity of water discharged in a given time.

The 30 cm galvanized iron tube with screens at either end was attached to the side of a motor coble below the water line. A hollow wooden structure extending above the surface and surrounding a perspex window in the top of the tube made it possible to observe fish in the tube. A current of water was created in the tube by starting up the motor-boat and in this way a maximum current of about 210 cm/sec. (7 ft/sec.) could be obtained. (This device was used to obviate the very large pump required to give a substantial flow through large tubes.) The speed in this case was taken as the speed of the boat measured by a low speed log, a correction being made for the slightly reduced speed of flow in the tube. This correction was determined by observing the backward drift of dead fish at different speeds of the boat.

2. By placing fish in troughs in either still or running water. Some data were obtained in the Hydraulics Department of Aberdeen University (by kind permission of Prof. J. Allen). Here fresh water could be pumped along a perspex trough 22 cm wide, 30 cm high, and about 6 m long. A maximum velocity of about 120 cm/sec. (4 ft/sec.) could be obtained, the rate of flow being controlled by an adjustable weir at the downstream end or by tilting the trough.

A trough, semi-circular in cross section, 60 cm in diameter, and about 10 m long was constructed of concrete culverting, in which still fresh or salt water could be kept and the fish stimulated into swimming along the trough.

3. By miscellaneous observations made from a research vessel. Artificial lights were used to aggregate fish near the surface where they could be easily observed. The speed of herring when returned to the sea after being tagged was also estimated by eye.

The experiments were carried out in the following way. In apparatus where a flow of water was used, the fish was first placed in the tube or trough in still water. The flow was then started. The fish nearly always orientated themselves against the current and the flow of water was increased until the fish began to fall back. As soon as its caudal fin touched the downstream screen it started to swim more actively, usually swimming up the entire length of the apparatus. This burst of swimming was timed with a stop watch and the speed could be calculated from a knowledge of the water velocity. A correction had to be made for the girth of the fish in small tubes. Where there was no water flow, as in the 60 cm trough, the fish were stimulated into a maximum effort usually by touching or holding the caudal fin. The forward movement was then timed with a stop watch, the tank being marked off at intervals of about 30 cm. In earlier experiments an attempt was made to stimulate the fish electrically (up to 250 v A. C.) but this was not found to be an effective means of stimulation, even in fresh water.

With each fish the following data were usually recorded: — length, weight, girth, temperature of water, temperature to which fish were acclimatized, details of swimming speeds (usually the fish were made to swim ten times their own length before a record was accepted), total distance swum, and time before the fish became exhausted (the criterion for this being that the fish could be picked up by the caudal fin without flexing the tail).

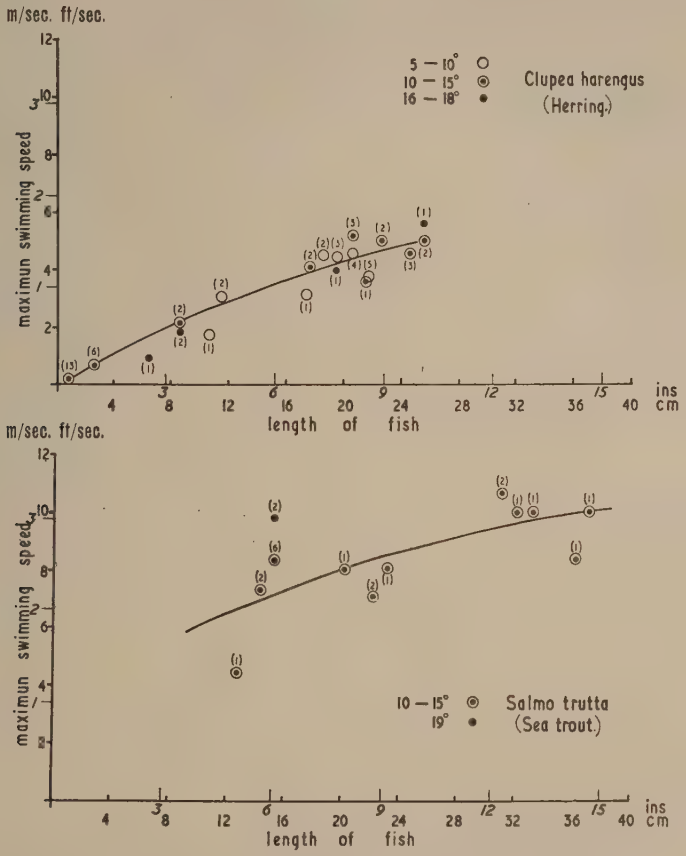

Figure 1. Showing the maximum observed swimming speeds of herring and sea trout.

Results

Swimming speeds

The maximum observed swimming speeds for herring and sea trout are given in Figure 1, and for cod, haddock, saithe, and whiting in Figure 2. Data from different temperature ranges are shown by appropriate symbols. The fish were divided into size ranges of 1 cm. Where more than one fish was used in a given size range the maximum speeds were averaged.

A comparison of the results for the six different species, length for length, shows that the sea trout was the fastest swimmer, herring and whiting the next, while cod, haddock, and saithe were the slowest. There was no consistent effect of temperature on the swimming speeds over the range of temperature used.

The swimming speeds observed in the other species are shown alphabetically in Table 1.

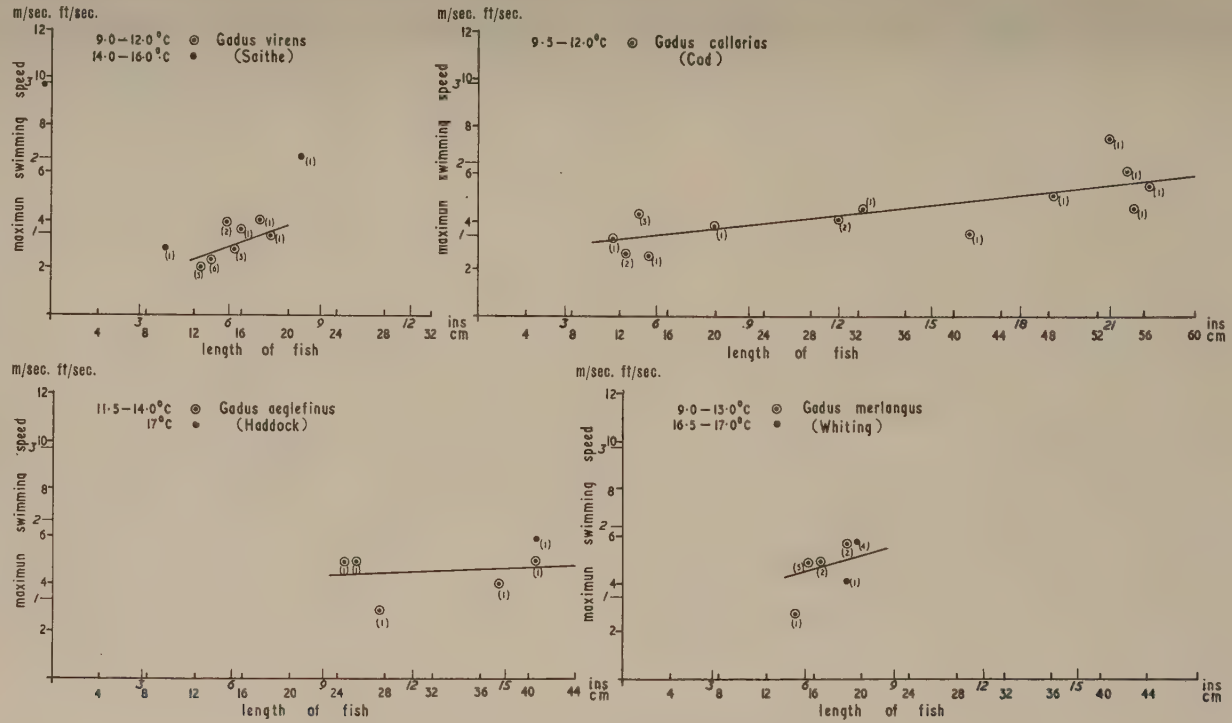

Figure 2. Showing the maximum observed swimming speeds of cod, haddock, saithe, and whiting.

Table 1

Maximum observed swimming speeds in various species

Species	Length (cm)	Number used	Maximum speed (cm/sec.)*) < 10° C	10–15° C	> 15° C
Blenny (*Zoarces viviparus*)	6·4	1	21	21	18
Brown trout (*Salmo trutta*)	12·5	1	84	–	–
	15	1	–	165	–
	19–20	2	123–204	–	–
	22–24	4	147–234	–	201
Butterfish (*Pholis gunnelus*)	10	1	–	–	30
Dab (*Pleuronectes limanda*)	7	1	–	9	–
	9	1	–	30	–
Eel (*Anguilla vulgaris*)	60	1	–	114	–
Flounder (*Pleuronectes flesus*)	27·5	1	105	–	–
Goby (*Gobius minutus*)	6–7	2	–	–	27
Goldfish (*Carassius auratus*)	8–10	7	126–150	69–123	78–111
	12·5	2	150–159	–	–
Gurnard (*Trigla* spp.)	18	2	–	129	135
Lemon sole (*Pleuronectes microcephalus*)	8	1	–	–	15
Mackerel (*Scomber scombrus*)	33–38	13	–	–	189–300
Plaice (*Pleuronectes platessa*)	6–8	4	–	–	6–30
	15	2	–	75–90	–
	22–25	10	–	81–129	114–120
Stickleback (*Gasterosteus spinachia*)	10	1	72	–	–
Sprat (*Clupea sprattus*)	7–8	4	24	18	36
	10	1	–	21	–
	12	about 50	–	60	–

*) Divide by 30·5 to give ft/sec. and 44 to give m.p.h.

Table 2

The total distances swum by various species before becoming exhausted

Species	Length cm (*L*)	Number	Temperature (°C)	Average total distance swum cm (*D*)	*D*/*L* (with S.E.)
Cod (*Gadus callarias*)	11·5–14·0	7	9–11	1,987	151 ± 29
	48·0–56·0	4	9·5–10·5	6,700	128 ± 11
Haddock (*G. aeglefinus*)	40·0	1	14·3	5,700	143
Saithe (*G. virens*)	14·0–21·0	6	9·0–14·0	4,820	293 ± 36
Whiting (*G. merlangus*)	14·5–18·0	11	9·0–13·0	4,107	254 ± 32
Mackerel (*Scomber scombr.*)	35·0–36·0	3	16·0–17·0	10,500	293 ± 86
Sea trout (*Salmo trutta*)	22·0–22·5	2	13·0	21,750	975 ± 220
	31·5–36·0	6	15·0–17·5	16,470	496 ± 80
Herring (*Clupea harengus*)	20·0–25·0	6	11·0–12·5	26,200	1,121 ± 98

Total distances swum

In order to relate the maximum observed swimming speed to the ability to avoid nets, observations were also made on the total distance swum by a fish (when continuously stimulated) before it became exhausted. The fish was taken to be exhausted when it could be removed from the water by the caudal fin without struggling. Table 2 shows the distance swum per unit length of fish (its stamina) for seven different species. It appears that the stamina of the gadoids and mackerel was about the same (with the possible exception of cod). Herring had a much greater stamina (about four times that of gadoids, the difference

between herring and saithe being significant at 0·1% level). Sea trout 31·5–36·0 cm long occupied an intermediate position (difference between them and saithe being significant at 5% level).

When the stamina of different sizes of a particular species are compared, as in sea trout and cod, it may be seen that the smaller fish appeared to have greater stamina (the difference is not significant for cod but is significant at the 5% level for sea trout).

Discussion

The values obtained for swimming speeds in these experiments should be considered as average maximum speeds, the highest value in a number of tests for each fish (where the fish swam at least ten times its own length) being taken. The values should be realistic from the point of view of the avoidance of nets, in that the speed was sustained over a relevant distance. In the same way the means used to stimulate the fish do not seem unrealistic in relation to the stimulus produced by a moving net.

These average maximum speeds are likely to be lower than values obtained over shorter distances. BAINBRIDGE (1958) using the very sensitive apparatus described by BAINBRIDGE and BROWN (1958), supports the view that fish up to 1 m long should be able to swim ten times their own body length per second. He gives an equation for his experiments relating swimming speed in cm/sec. (V) to body length in cm (L) and frequency of tail beat in beats per second (f):—

$$V = \frac{1}{4} L (3f - 4)$$

The relationship between body length and swimming speed for herring in our experiments (for which most data are available) takes the form: —

$$V = 7{\cdot}6\, L^{0{\cdot}94}$$

The slope of the line is not significantly different from unity. Thus herring swam about $7\frac{1}{2}$ times their body length per second using the apparatus and methods described for these experiments.

While there was no consistent effect of temperature on swimming speeds in our experiments, it is interesting to note that the cruising speed of fish may vary with temperature (FRY and HART, 1948; BRETT, HOLLANDS and ALDERDICE, 1958).

Acknowledgements

Thanks are due to Mr. D. H. GIBSON of the Engineering Department of Aberdeen University, Mr. T. A. STUART of the Freshwater Fisheries Laboratory, Pitlochry, and Mr. R. JONES of this laboratory who assisted in some of the earlier experiments. Mr. STUART also provided brown trout for some of the work.

Summary

1. The average maximum swimming speeds of a number of fish, mainly marine species, have been measured.

2. The values for gadoid species were as follows: — *Gadus callarias* (12–56 cm) 75–210 cm/sec., *G. aeglefinus* (25–42 cm) 75–180 cm/sec., *G. merlangus* (14–20 cm) 75–160 cm/sec., and *G. virens* (9–21 cm) 60–200 cm/sec.

3. The values for the other main species used were as follows: — *Clupea harengus* (1–25 cm) 3–170 cm/sec., *Salmo trutta* (sea trout) (12–38 cm) 135–320 cm/sec., *Salmo trutta* (brown trout) (12–24 cm) 84–234 cm/sec., *Carassius auratus* (8–13 cm) 69–159 cm/sec., *Scomber scombrus* (33–38 cm) 189–300 cm/sec., and *Pleuronectes platessa* (6–25 cm) 6–129 cm/sec.

4. There was no obvious correlation between average maximum swimming speed and temperature.

5. Observations made on the total distance swum at near average maximum speed by fish before exhaustion, showed that gadoids could swim 130–300 times their body length and *Clupea harengus* 1100 times, *Salmo trutta* (sea trout) 500–1000 times, and *Scomber scombrus* 300 times their body lengths respectively.

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Hake Tagging in Europe and the United States, 1931—1958

By

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Introduction

Fish of the genus *Merluccius* are difficult to tag successfully. Attempts have been made in Europe on the European hake (*M. merluccius* L.) and in the United States on the silver hake (*M. bilinearis* Mitchill) using a variety of tags and tagging methods with few or no returns.

Hickling (1933) believes that the lack of returns is largely due to the hake's inability to survive rough treatment and the irreversible distention of the gas bladder as a result of being brought to the surface in the trawl. Although there is no question as to the seriousness of these difficulties, our experiments with silver hake show that a suitable tag and tagging technique are as essential as the condition of the fish when tagged. It is the purpose of this report to summarize the experiments conducted in Europe and in the United States and to describe our recent experiments on the silver hake along the Atlantic coast.

European Experiments

Investigators in Europe have tagged hake with varying degrees of success since 1931. Since the European species is usually found in depths of over 30 fm, the early trials were conducted with fish captured in an otter trawl. The hake were in poor condition, with many of the scales removed by rubbing against the gear and with distention of the gas bladder. The returns from these trawl-caught fish were from 0·3 to 1·4%.

J. A. Gulland (personal communication) of the Lowestoft Laboratory, England, during 1957, used the Lowestoft tag (Fig. 1) on hake captured with a Danish seine. The tag is a soft, yellow plastic flag attached to the back of the fish by a braided nylon loop. For the first time a significant increase was obtained in the number of returns (6·5%) using this tag and method of capture. Although the returns are still not so high as for many other species such as cod, haddock, or flounders, these results are encouraging. The results of European experiments from 1931–1957 are summarized in Table 1.

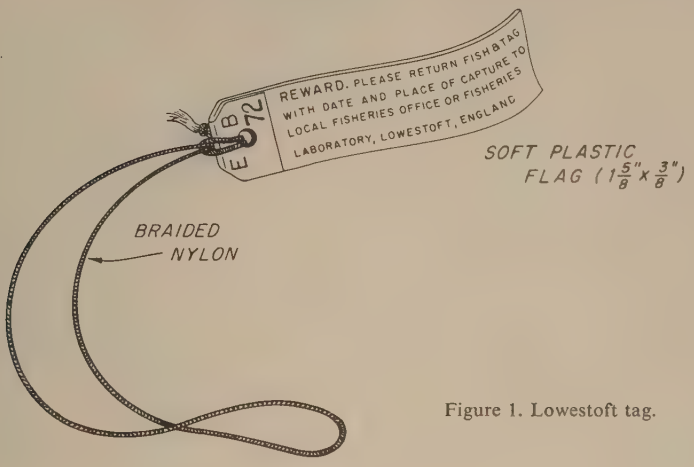

Figure 1. Lowestoft tag.

Table 1

A summary of European tagging experiments from 1931–1957

Tag	Gear	Number tagged	Number recovered	Percentage returns	Area	Reference
Petersen.....	Trawl	70	1	1·4	South of Ireland	Russell, 1931
?.....	Trawl	800	0	0	South of Ireland	Davis, 1932
Lea.....	Trawl	300	1	0·3	South and west of Ireland	Gulland[1])
Lowestoft	Danish seine	307	20	6·5	Irish Sea	Gulland[1])

[1]) Personal communication.

United States Experiments

Investigators in the United States have also experienced difficulty in tagging hake captured in the trawl. D. Merriman (personal communication) of the Bingham Oceanographic Laboratory had disappointing results from tagging trials conducted in Rhode Island Sound in 1946 and 1947 (Table 2). However, in 1954, J. R. Clark (personal communication) of the U.S. Fish and Wildlife Service Laboratory, Woods Hole, Mass. tagged 266 hake from a trawl, and the results show that four (1·5%) were recovered. This was the first time that any tag returns were obtained from trawl-caught silver hake in this country.

Since the silver hake, unlike its European counterpart, is found in shoal water during the spring and summer months, experiments were conducted with fish captured from floating trap nets located along the coast from Massachusetts to New Jersey. These fish were in excellent condition and not subjected to the rapid changes in pressure or rough handling which are characteristic of trawl-caught fish. This also gave the investigators an opportunity to experiment with several types of tags. The results from using the Petersen disc with

Table 2

A summary of the United States tagging experiments from 1946–1956

Tag	Gear	Number tagged	Number recovered	Percentage returns	Area	Source
Petersen	Otter trawl	126	0	0	Rhode Island Sound	MERRIMAN[1]), 1946
Petersen	Otter trawl	22	0	0	Rhode Island Sound	MERRIMAN[1]), 1947
Petersen	Otter trawl	266	4	1·5	Cape Cod Bay	CLARK[2]), 1954
						Current Experiments Woods Hole
Petersen	Otter trawl	36	0	0	Ipswich Bay	1955
Petersen	Trap	39	0	0	Rhode Island Sound	1955
Lea dangler	Trap	22	2	9·1	Rhode Island Sound	1955
Petersen	Trap	35	0	0	New Jersey	1955
Lea dangler	Trap	6	0	0	New Jersey	1955
Atkins monofilament loop	Trap	347	0	0	New Jersey	1956
Petersen	Trap	216	1	0·5	New Jersey	1956
Atkins monofilament loop	Trap	974	5	0·5	Ipswich Bay	1956

[1]) Personal communication.
[2]) Personal communication.

a steel pin, Lea dangler (WISE, 1958), and an Atkins tag with a monofilament nylon loop during 1955 and 1956 showed that these tags were not suitable (see Table 2). Since the hake were in excellent condition when captured, it was assumed that they had died from the tagging injury caused by the steel pin or by the monofilament nylon pulling through the soft flesh.

In 1957, a plastic tube tag described by WILSON (1953) was modified by us and used successfully on the silver hake. The modified tag consists of an 8-inch piece of 0·036 inch O.D. yellow vinyl plastic tubing with an Atkins tag (ROUNSEFELL and KASK, 1943), 22 mm by 9 mm by 1 mm thick, attached to one end of the tubing with a figure eight knot (Fig. 2). The corners of the tag were rounded to eliminate the sharp edges which might injure the fish. A $4\frac{1}{2}$ inch stainless steel rod, 0·064 inch O.D., was used as a needle. One end of the rod was ground to a point and the other end turned down so it could be forced into the plastic tubing. The needle with the complete tag attached was inserted through the flesh at the base of the second dorsal fin. The tubing was then separated from the needle, and a figure eight knot was tied at the opposite end

Table 3

A summary of tagging experiments during 1957 and early 1958

(All experiments made using the Atkins tag with vinyl plastic tubing)

Gear	Tagged	Number recovered	Percentage returns	Area
Trap net	681	56	8·2	Ipswich Bay
Trawl	1,088	54	5·0	Georges Bank
Trawl	183	1	0·5	Stellwagen Bank
Hook and line	200	18	9·0	Scotland Lightship

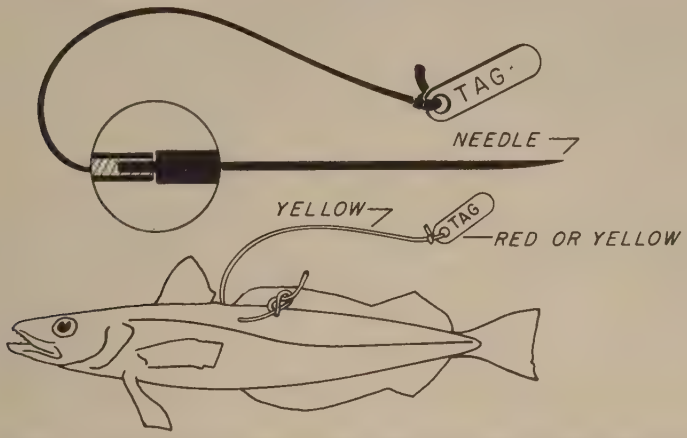

Figure 2. Plastic tubing tag used on silver hake (*Merluccius bilinearis* Mitchill).

from the Atkins tag to prevent the tubing from slipping out. Four experiments were conducted with this type of tag using fish caught by a variety of methods. The results are summarized in Table 3.

The first experiment was conducted in June 1957, at a trap net located in six fms of water in Ipswich Bay, Massachusetts (42°41′ N latitude, 70°39′ W longitude). A total of 681 silver hake were tagged, and 56 (8·2%) have been recovered. Fifty-five tagged fish were recovered during the first 28 weeks and one fish after 56 weeks. Whether the other tagged fish moved to an area not exploited by the fishing fleet or died from the tagging injury is unknown.

The second experiment with the modified tag was conducted in July 1957 with trawl-caught fish on the U.S. Fish and Wildlife Service research vessel "Albatross III" on Georges Bank (41°41′ N latitude, 68°18′ W longitude) in 25 fms. Three precautions were taken to avoid damage to the fish. First, a fine mesh cover was placed over a 5-inch mesh cod-end to permit the silver hake to pass from the cod-end and thus escape injury from the skates and other large fish which are retained by the cod-end. Second, the towing speed of the vessel was reduced so that the hake would not be compressed in the cover. Third, the haul-back speed was also reduced in order to avoid gas bladder damage in the fish. After the fish were brought on board the vessel, the cover was placed immediately in a large wooden tank filled with sea water. The cover was then opened, and the fish were released into the tank. Despite these precautions, only about one-third of the hake were judged to be in a condition suitable for tagging. During the two-day tagging operation, 1,088 silver hake were tagged. Fifty-four fish (5·0%) were recovered within one month, but none have been recovered since.

The third experiment was conducted in September 1957, with trawl-caught fish on the research vessel "T-79" on Stellwagen Bank (42°11′ N latitude, 70°19′ W longitude) from 18–30 fms. This experiment was conducted without the precautions used in the second experiment. Of 183 hake tagged, only one (0·5%) has been recovered, and this within one month of tagging.

The fourth experiment was conducted 8. February 1958, on a sport fishing party boat near Scotland Lightship (40°27′ N latitude, 73°55′ W longitude) off

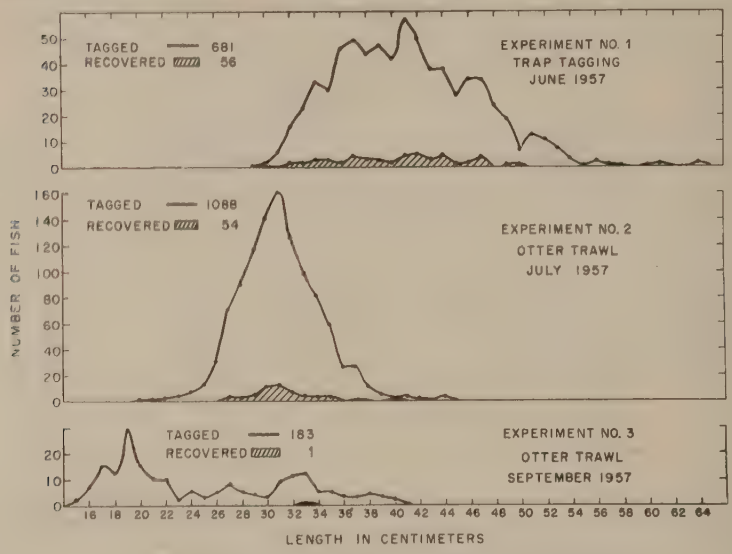

Figure 3. Length-frequency distribution of silver hake tagged and recovered during 1957.

Sandy Hook, New Jersey in approximately 10 fms to test this tag on silver hake captured with hook and line. After the fish were brought on board the boat, they were placed in a small metal tank, tagged, and released. The results show that out of 200 fish tagged, 18 (9·0%) were recovered within two months.

Length-Frequency Distribution

The length-frequency distributions of the silver hake tagged during the first three experiments are shown in Figure 3. The lengths of fish recovered in the first two experiments were distributed throughout the range of the fish tagged. This would indicate a lack of differential mortality associated with the length of fish. Much smaller hake were tagged during the third experiment. Due to the generally poor results obtained from this tagging, no conclusion can be reached about the lack of returns from the smaller size categories.

Summary and Conclusions

1. After many unsuccessful attempts to tag hake in Europe and the United States, the results of recent experiments have been encouraging.

2. A yellow, soft plastic flag with a braided nylon loop was used on the European hake (*M. merluccius*) captured with a Danish seine. The returns increased from 0·3% to 6·5%.

3. A variety of tags were used in the United States on silver hake (*M. bilinea-*

ris) with few returns prior to 1957. During 1957 and early 1958, an Atkins tag fastened to the fish with vinyl plastic tubing was used with improved results. Three methods of capture were used to test this tag with the following returns: the floating trap, 8·2%; the otter trawl, 5·0%; and the hook and line, 9·0%.

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Further Experiments on Mussel Purification

By

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Introduction

The purification of mussels in two overnight baths of clean sea water has been a commercial practice at Conway for many years (DODGSON, 1928). More recently a similar method using slightly polluted water has been used at Teignmouth (REYNOLDS, 1956). The present work was originally intended to find out at what level the initial pollution of the water became a limiting factor. This limiting level proved to be lower than had been expected, and the scope of the investigation was then extended to devise a method by which water having a considerably higher level of pollution could be used without resorting to chemical sterilization of the sea water. The advantage of this is that it enables one to dispense with a water storage tank, and thus considerably reduces the capital cost of the mussel purification installation.

Experimental Method

The first part of this work was done on a small scale. Vessels holding 10 l of water were used, and 10 mussels were placed in each, the same volume of water per mussel as that used for commercial cleansing in the Conway tanks. Experiments were run at controlled temperatures of 0, 5, 10, 15, and 20°C, the vessels being held in a water bath where the temperature was maintained to within 0·5°C of the required value. The sea water used was taken from the Conway estuary at about High Water and was always of a fairly high salinity (28 $^0/_{00}$ or more). At this state of the tide the water was usually only lightly polluted and so it was necessary to increase the pollution. This was done by adding a quantity of a culture of *Eschemchia coli*, a more convenient method than the use of crude sewage. A comparison of the rate of die-off in sea water of bacteria from the two sources showed that those from the culture did not die very much more rapidly than those from sewage, and that over half survived for 18 hours or more. It is reasonable to assume that results obtained using cultured bacteria will be applicable to naturally polluted sea water. After some trials it was found that 1 ml of a 1:10,000 dilution of a 22 hour peptone water culture of *E. coli* would give a pollution of approximately 10 *E. coli* per

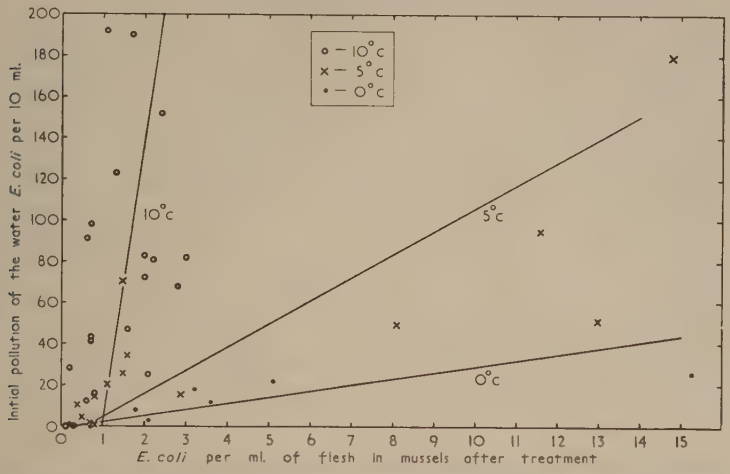

Figure 1. The relation between the initial pollution of the water and the final pollution of the mussels after two overnight baths.

10 ml of sea water, when it was added to 10 l of sea water. After thorough mixing the water was sampled to determine the actual degree of pollution.

Ten mussels, washed free from external mud, were placed in each vessel. To reduce physiological variations to the minimum, they were all taken from the same bed and were between 2·5–3 in. (6·3–7·6 cm) in length. This size was chosen as being representative of good marketable mussels. In order to avoid ill-effects which might be caused by sudden changes of temperature, experiments at low temperature were made in the winter and those at higher temperature in the spring and early summer.

In each experiment the mussels were given two overnight baths of sea water, the degree of pollution for the two baths being as similar as possible. In assessing the results, the initial pollution of the water for the second night has been taken as the significant one. A sample of untreated mussels was examined at the start of each experiment, and the ten mussels were examined individually at the end of the experiment. All bacteriological examinations were done by the method of Clegg and Sherwood (1947), as modified by Reynolds and Wood (1956).

Results

The results of these experiments are shown in Figure 1. The initial degree of pollution of the water for the second night has been plotted on the vertical axis and the final degree of pollution of the mussels on the horizontal axis. For each temperature the results have been statistically examined to see if a correlation is likely to exist between the two. In each case also the equation for the regression line which gives the best estimate of the final pollution of the mussels for a given initial pollution of the water, has been calculated.

At 0°C the correlation between the initial pollution of the water and that of the mussels at the end of the experiment is significant beyond the ·001 level.

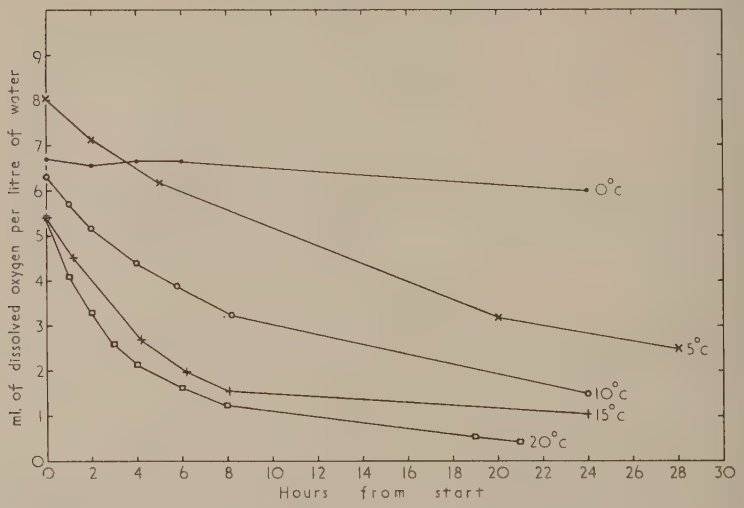

Figure 2. Rate of use of dissolved oxygen by 10 mussels in 10 litres of sea water.

Two important points emerge from Figure 1. Firstly, that mussel purification can be done in water at 0°C provided that it is initially free from pollution, and, secondly, that the final degree of pollution of the mussels increases very rapidly with rise in the initial pollution of the water. At 5°C the significance of the correlation falls to between ·02 and ·01. At this temperature the mussels are better able to cope with increased water pollution. At 10°C these tendencies are more marked, the significance of the correlation falling to ·02. At 15 and at 20°C there is no significant correlation between the initial pollution of the water and the final pollution of the mussels.

Dissolved oxygen

In the previous paper (REYNOLDS, 1956) it was suggested that the dissolved oxygen content of the water might be an important factor in mussel purification, and a brief theoretical discussion was given of the effect of raised temperatures. In this work an attempt has been made to determine more precisely the effect of temperature on the dissolved oxygen content of the water and the rate at which mussels use up the oxygen. Experiments were done over the same range of temperatures (0–20°C), using 10 mussels in 10 l of sea water. The dissolved oxygen content was measured at the beginning of the experiment and at 2, 4, 6, 8, 20, and 24 hours after the start. Dissolved oxygen determinations were made by the azide modification of WINKLER's method (A.P.H.A., 1946). The results are shown in Figure 2 where the number of millilitres of dissolved oxygen per litre of water is plotted against the number of hours from the start of the experiment. It may be noticed that the initial concentration of oxygen is not always the same as the value for saturation at that particular temperature. This is due to the fact that on many occasions the water had either to be heated or cooled to the required temperature, and did not always have time to reach equilibrium before the start of the experiment.

It is clear that at 0°C the rate of using of oxygen is very slow indeed, and that present in the 10 l of water would last the mussels almost indefinitely. At 5°C oxygen is used up much more rapidly, but at the end of 24 hours there are still practically 3 ml/O_2/l of sea water left. At 10°C the oxygen is reduced to 3 ml per litre at the end of 10 hours. At 15°C this value is reached in less than 4 hours, and at 20°C at about 2·5 hours. This value of 3 ml per litre has been taken purely for the purpose of illustrating the much greater use of oxygen at higher temperatures, and it is not intended to suggest that this particular value is in any way critical. It is, however, abundantly clear that at both 15 and 20°C the dissolved oxygen content is very seriously depleted at the end of the first few hours.

Since the dissolved oxygen is used up very rapidly at 15°C and above, and it was at these temperatures that no significant correlation was found to exist between the initial pollution of the water and the final pollution of the mussels, a few experiments were done in which a supply of air was bubbled continuously into the vessels. This was sufficient to maintain saturation with oxygen at 15°C and approximately 85% saturation at 20°C. The results of these experiments are illustrated in Figure 3. At 15°C the correlation between initial water pollution and final mussel pollution is significant at beyond the ·001 level, and at 20°C between the ·01 and ·001 level. The lower significance at 20°C may be due to the smaller number of observations at that temperature.

In the introduction it was stated that one of the main aims of the work was to find out to what extent the pollution of the water can be raised before purification of the mussels ceases to be satisfactory. The definition of "satisfactory purification" needs some consideration. Broadly speaking, any sample of mussels which comes into Sanitary Grade I (0–5 *E. coli* per ml of flesh) is acceptable in all markets (Sherwood and Scott Thomson, 1953). Since even with the most carefully controlled system some variation in the final product is inevitable, it is necessary to arrange the process so that the average degree of pollution of the purified mussels is well inside the upper limit (5 *E. coli* per ml of flesh), if the normal variation is not to result in some samples failing to come into Grade I. An estimate of the extent of the normal variation to be expected in a commercial process may be made from an examination of the results of routine examinations of Conway purified mussels, and of Teignmouth purified mussels. Fifty consecutive routine samples of Conway mussels gave an average final pollution of 0·16 *E. coli* per ml, with a maximum of 1·2. In this case the maximum was 7·5 times as great as the mean. Fifty routine samples of Teignmouth mussels gave an average final pollution of 0·74 *E. coli* per ml, with a maximum of 4·5, just within the limit of Grade I and 6·2 times as great as the mean. Since at Conway the highest value was about 7 times as great as the mean, it appears that the variation at Teignmouth is not exceptional, and an average figure of 0·74 (or in rounder figures 0·75) *E. coli* per ml is as high a mean figure as can be tolerated if all samples are to come into Grade I. If the mean value were raised to 2 *E. coli* per ml and the variation remained the same, the highest values would be about 14 *E. coli* per ml, just within the limits of Sanitary Grade II. Further examination of the routine samples discussed above suggests that on this basis about 94% of the samples would be in Grade I, 6% in Grade II. Further raising of the mean value would result in an increased likelihood of some samples falling in Grade III. One may then suggest that an average pollution of 2 *E. coli* per ml of flesh in the purified mussels is the highest that can be considered as satisfactory purification and that 0·75 is the highest

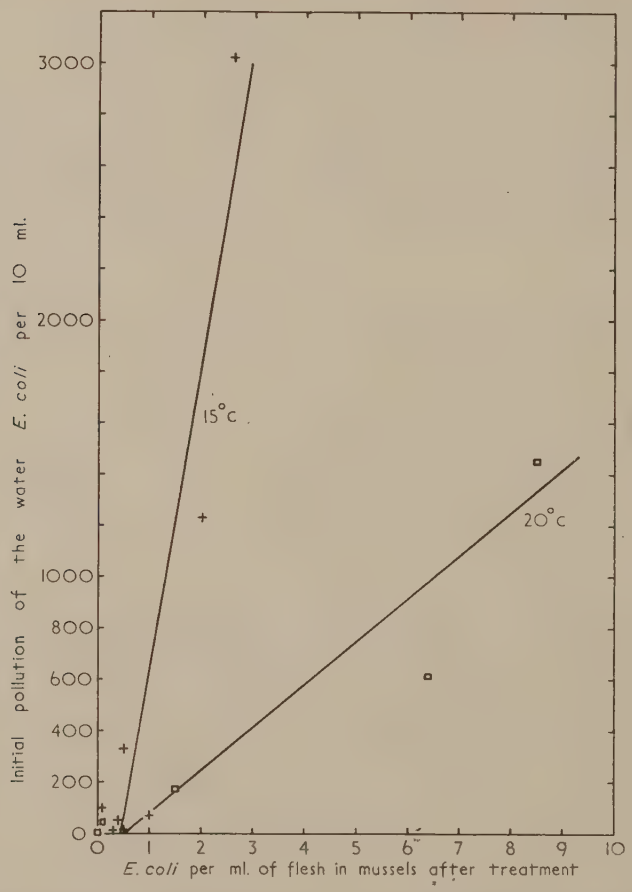

Figure 3. The relation between the initial pollution of the water and the final pollution of the mussels after two overnight baths with continuous aeration.

value that will give reasonable certainty that all samples will come into Sanitary Grade I.

The question then arises as to what degree of initial water pollution will give these final results. Figure 1 shows clearly that an average final mussel pollution of 0·75 *E. coli* per ml of flesh can only be obtained with almost unpolluted water, a result to be expected since the water used at Teignmouth usually contains less than 5 *E. coli* per 10 ml. The more lenient standard of 2 per ml can be achieved with water containing 6 *E. coli* per 10 ml at 0°, 15 at 5°, and 130 at 10°C, above this temperature the process becomes unreliable. At 0°C the functioning of the mussel is extremely slow, byssus formation hardly takes place at all, and the dissolved oxygen in the water is consumed very slowly (Figure 2). It is probable that the oxygen supply would allow functioning to

go on for a full 48 hours. If the water were left unchanged for 48 hours the mussels would be able to deal with a higher bacterial concentration, but one would not expect it to be more than doubled, i.e., from 6–12. At 5°C in these experiments the oxygen was very greatly diminished at the end of 24 hours, the same result has been found in the commercial purification tanks at Conway, so there is no possibility of dealing with higher bacterial concentrations by increasing the time of contact between the mussels and the water. Hence, even on the more lenient standard of an average count of 2 *E. coli* per ml of flesh in the purified mussels, fairly clean water, 10–15 *E. coli* per 10 ml, is needed when temperatures are around 5°C as they often are during the mussel season.

So far discussion has been limited to the lower temperature range of below 10°C. At 15° and 20°C other problems arise. If the water is not aerated the results obtained are very variable. At 15°C this variability is well illustrated in the first pair of experiments in which the water was initially clean for the second night and the mussels highly polluted. In both cases most of the mussels purified themselves, but in the first sample one mussel had 19 *E. coli* per ml, giving an average for the sample of 1·9, and in the second sample one mussel had 52, which was largely responsible for the average of 6·2. Almost without exception in the experiments at 15°C a high average count was caused by one or two unclean mussels in an otherwise satisfactory sample. Since the oxygen is quickly used up at this temperature it appears that if a mussel is slow to start functioning it may be too late to purify itself.

At 20°C the exhaustion of dissolved oxygen is more rapid still and the final results appear to depend more on the initial pollution of the mussels than on the water. Some of the highest final counts were obtained from very polluted mussels in relatively clean water. The wide variation in the final counts among the ten mussels making up a sample is very evident. The view that this wide variation is connected with the depletion of dissolved oxygen is supported by the results obtained with continuous aeration. In these experiments not only could the mussels deal with many more bacteria but the variation within the sample was considerably reduced. The fact that very much better results were obtained when the supply of oxygen was maintained strongly suggests that the functioning of mussels is impaired by lack of oxygen.

48 hour bath with re-aeration

As it had been found that at low temperatures satisfactory results could only be relied on if the initial water pollution was in the region of 5–10 *E. coli* per 10 ml, the second half of the work was aimed at devising a method whereby more heavily polluted water could be used. The logical step seemed to be to increase the duration of the time in which the mussels were in contact with the water and to avoid de-oxygenation of the water by re-aerating it as necessary. At the same time a change was made in the scale of the experiments. An open air tank approximately 11 × 2 × 1 ft deep (3·5 × 0·7 × 0·3 m) holding 600 l of water and 600 mussels was used. This larger tank was not amenable to control of the water temperature, but the scale of operations was nearer to commercial practice and the larger size was more convenient for the accurate adjustment of aeration.

Aeration was done by pumping water out of one end of the tank and squirting it back in again. By flattening the end of the delivery tube and arranging the jet so as to strike the surface of the water almost horizontally, efficient aeration

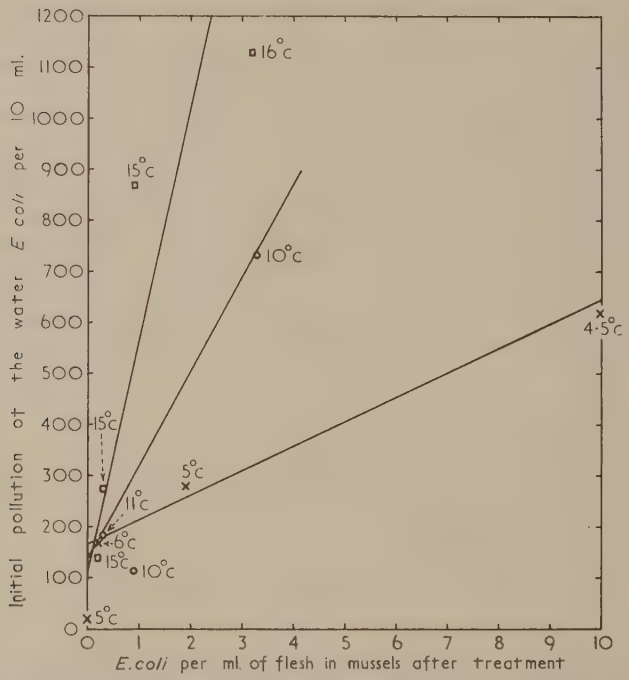

Figure 4. The relation between the initial pollution and the final pollution of the mussels after one 48 hour bath in sea water with aeration after the first night.

and circulation was achieved without disturbing the water unduly. This latter point is important as it is essential to avoid breaking up the mussel faeces and thus redistributing the polluting bacteria in the water. The pump used was capable of pumping the 600 l of water in half an hour; trials showed that water which had been partially deoxygenated by mussels could be restored to about 90% O_2 saturation in this time. This period of aeration was used throughout this series of experiments. The water was run in from another tank. Pollution in the form of sea water taken from a sewage outfall, was added as necessary, the water was then aerated for half an hour and sampled for *E. coli* and for dissolved O_2. A sample of mussels was also taken. The next morning the water was sampled again, re-aerated for 30 minutes, and sampled again. After the second night the water was sampled again; mussel samples were also taken after both one and two nights' treatment.

As has been mentioned, control of the temperature was not possible in this larger tank. During an experiment the temperature rarely changed by more than a degree or two and it has been possible to group the experiments into those done at approximately 5°, 10°, and 15°C respectively. The results are shown in Figure 4, where the actual temperature of each experiment is shown by each point. In this case the lines illustrating the relation between initial pollution of the water and final pollution of the mussels have been fitted by eye. As was found in the earlier experiments it is possible to put a line through the points

for each temperature and in general these latter results show less tendency to scatter than did the earlier ones. There are, as yet, no results for temperatures below 4·5°C, so that one cannot make a full assessment of the value of this method of purification. So far it appears to be very promising. With initial water pollution up to 200 *E. coli* per 10 ml all four final mussel pollutions were less than 1 *E. coli* per ml of flesh, and three of them were less than the 0·75 suggested earlier as being necessary to ensure that all samples will fall in Grade I. If the initial water pollution is raised to 400 per 10 ml, good results may still be expected at 10°, and 15°C, but at 5°C the final pollution of the mussels may be expected to approach the upper limit of Grade I. As a working guide it appears that water containing up to 200 *E. coli* per 10 ml may safely be used at temperatures between 5° and 15°C. At lower temperatures the safe limit of initial water pollution may be expected to be lower unless the duration of cleansing is extended. Further experiments are planned to elucidate this point.

Summary

Mussels were purified in 10 litre vessels allowing 1 litre of sea water per mussel. Two overnight baths in water of known *E. coli* content were given. Experiments were made at controlled temperatures of 0°, 5°, 10°, 15°, and 20°C.

At the lower temperatures a linear relation was found between the initial pollution of the water and the final pollution of the mussels. This was not so at 15° and 20°C unless the water was continuously aerated.

The rates of using oxygen by 10 mussels in 10 l of water at temperatures from 0° to 20°C were measured. At 0°C approximately one-twelfth of the dissolved O_2 was used in 24 hours, at 15° and 20°C approximately half was used in 4 hours.

The variation to be expected in the results of examining samples of purified mussels is discussed and it is suggested that the average value should not exceed 0·75 *E. coli* per ml of flesh if all samples are to come into Sanitary Grade I. If the average value is between 0·75 and 2·0 *E. coli* per ml of flesh over 90% of samples will come into Grade I, and the remainder in Grade II. During the winter months water temperatures of about 5°C are common. Under these conditions the use of two overnight baths can only be expected to give satisfactory results when the sea water does not contain more than about 10 *E. coli* per 10 ml.

Further experiments are described in which the mussels were given one 48 hour bath in sea water and the water was re-aerated after the first night. Under these conditions at temperatures from 5° to 15°C satisfactory results were obtained with water containing up to 200 *E. coli* per 10 ml.

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Methods for Marking Whelks (*Buccinum undatum* L.)

By

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Introduction

Various methods have been used for marking gastropods for field studies. *Urosalpinx* has been painted with oil paint (FEDERIGHI, 1931) and quick drying lacquer paint (HANCOCK, in press), and the spires of *Nucella* were dipped in cellulose paint and the shell lips notched by a carborundum wheel (MOORE, 1938). Both genera are able to survive exposure to air for long periods, *Urosalpinx* for as much as eight days (HANCOCK, in press) so that rapid drying is not essential. Unlike these, however, the commercial whelk (*Buccinum undatum* L.) is not equipped with protective reactions, and, when removed from water, instead of withdrawing into the shell, it exposes almost a maximum of body surface and accelerates to a high degree the rate of loss of water (GOWANLOCH, 1926). For this reason, a more rapid method of marking is required. The following method evolved for marking whelks for a recapture experiment in the field has proved successful.

Marking Methods

First, the relatively thick periostracum and encrusting organisms were removed by hand with a wire brush from the spire, which was then wiped clean with a cloth. The whelks were then placed firmly, spire uppermost, in wooden frames covered by chicken wire netting of $\frac{3}{4}''$ and $1''$ meshes. Later, grids made from $\frac{3}{4}''$ and $1''$ mesh $\frac{1}{8}''$ galvanized wire proved even more suitable. These were particularly important when marking on the deck of a boat, which was often very unsteady, sometimes with sea breaking over the decks. The foot of each whelk hung vertically downwards and was then almost completely shaded from strong sunlight by the shells of its neighbours. Dipping the spire in paint was unsuitable because, when dried spire uppermost, the excess paint drained onto the flesh of the whelk, while, if kept spire downwards, the paint became unevenly distributed. In this position, also, mucous draining from the whelks interfered with drying of the paint, and the flesh of the whelks was exposed to the sun. The spires were painted with Swancoat additive-treated paint, a proprietory brand of Thomas Swan and Company, which has the advantage that it

Figure 1. Marked whelk, showing painted spire, pencilled label, and scrubbed lip of shell with new growth along the edge and tip. (Photo: P. J. WARREN.)

can be painted onto a surface damp from sea water, and dried under normal conditions in about one hour. Drying took a little longer in wet weather when it was necessary to keep the whelks under cover from the time the spire was cleaned. The paint used was in bright colours, readily distinguishable from the normal mud-brown of untreated shells. This is important because recaptures from commercial fisheries depend less on identification by scientists than by fishermen, who are asked to return coloured whelks from their daily catches.

Coloured whelks have been returned after a completed year under the sea, with the paint very easily recognizable, and in many cases appearing as fresh as when applied. Barnacles and bryozoans occasionally settled on the painted surfaces, and this should be remembered when choosing areas in which there is a heavy settlement of encrusting organisms which might tend to obscure the paint. The marking process has lately been speeded up by the use of power-driven wire brushes. Employing six men, the spires of 1,000 whelks have been cleaned and painted in less than three hours. The time of exposure required for painting and drying varied with weather conditions, but whelks returned to sea water after being exposed for periods of up to four to five hours soon took up moisture again and recovered quickly. This was observed in aquarium tanks, and also when bad weather occasionally prevented immediate relaying in the place of capture and batches of coloured whelks were retained overnight in a keep pot in the sea. The speed of recovery depends, of course, on atmospheric conditions during the exposure period. At least a short period of

recovery in sea water, usually in buckets on deck, was considered desirable to help reduce the period of inactivity of whelks returned to the sea bed, and so give less encouragement to crabs and other predators.

The method previously described by Conover and Pierce (1956) for labelling oysters with paper labels and a transparent adhesive has proved successful also for whelks. The whelks were first painted as described previously. A small area of the shell was then smoothed using a rotating sandstone and a pencilled label attached close to the suture and near to the edge of the largest whorl (see Figure 1). Labelled whelks have been returned after one year in the sea. Under rough sea conditions however, the use of adhesive and tiny paper labels proved to be somewhat difficult, and was slow considering the need for returning the whelks quickly to sea water. A quick method for establishing the length of whelks at the time of marking was required. Notching the shell with a file, various saw blades and a carborundum wheel were tried, but the shell lip is very brittle and fractured easily, usually along its length. In any case, it is believed that damage to the shell lip will produce abnormal growth-rates. It was decided that if the shell lip was scrubbed, like the spire, subsequent new growth should be distinguishable by the characteristic periostracum. A few were cleaned with a wire brush in this way, and on recapture the size at marking and the growth increment could easily be determined (Figure 1). One advantage was that any damage to the shell lip which had occurred during marking or returning to the sea bed was usually obvious, and could be taken into account when considering growth-rates. In cases of very rapid growth, the position of the siphonal tip at marking was obscured by the new growth, but it was possible to get an accurate measurement of growth from the spiral increment, and growth in length could be calculated from other shell length constants. It seems unlikely that scrubbing the shell lip would interfere with normal growth, but this and the effects of damage to the shell lip by breakage or notching are being investigated.

Summary

Methods used with success for marking whelks for field studies have been described. These included painting the shell with a quick drying paint, attaching numbered paper labels by adhesive to the shell, and scrubbing the shell lip as a means of determining subsequent growth increments.

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Editorial Notice

Current Bibliography

This issue of the Journal will be the last to contain the *Current Bibliography* section, which has been a feature of this publication since E. J. ALLEN prepared his *Selected Bibliography of Marine Bionomics and Fishery Investigation* in 1926. Since that time the number of articles pertaining to one or other aspects of fisheries science increased greatly year by year. With the establishment in post-war years of laboratories in almost every country in the world and the formation of several international regional fisheries councils and commissions, the growth of literature accelerated, and it has become increasingly difficult for the International Council to maintain the regular production of a useful bibliography without imposing an intolerable burden on the working scientists whose task it has been to search periodicals and prepare the manuscript. For this reason we welcomed the publication, by the Biology Branch of FAO Fisheries Division, of the *Current Bibliography for Fisheries Science* which started early in 1958 and has continued to be issued monthly since then (from January 1959 under the new title *Current Bibliography for Aquatic Sciences and Fisheries*). By gaining the enthusiastic co-operation of libraries in many fisheries laboratories, including that at Lowestoft where our Current Bibliography was prepared, and contributing the efforts of their own permanent staff, FAO have been able to arrange for a more comprehensive coverage of fisheries literature than we could achieve by ourselves. This broad coverage is perhaps more important now than ever before, at a time when methods, techniques, and theories of general application are taking the interest of research workers everywhere.

The FAO bibliography is at present prepared as a mimeographed document, but we have every reason to hope that that Organization will find the means of ensuring its continuation in a more permanent form. It is indexed cumulatively by author and by taxonomic and geographic categories, and we have been assured that as soon as possible a subject index will be added. It also contains useful supplementary notes on forthcoming meetings, translations of papers, and other matters of interest to the readers of the Journal. The *Current Bibliography for Aquatic Sciences and Fisheries* is distributed free to fisheries research units and institutions throughout the world, including all those which have been until now on the mailing list of the ICES Current Bibliography. Means are being explored by which it may be sent, on a subscription basis, to individual workers. We are confident therefore that the bibliographic

requirements of our readers will continue to be well served, and we urge our readers to do all they can to assist FAO in this co-operative task.

It is a pleasant duty to express my thanks to Commander J. R. Lumby who devoted so much time and skill to the promotion of the Current Bibliography during his time as editor of the Journal, and to Mr. A. R. Margetts who has been responsible for the important task of selecting and collecting the bibliography.

Charlottenlund, May 1959

Árni Friðriksson

Letters to the Editor

The Mode of Action of the Vigneron-Dahl Modification of the Otter Trawl

In his paper in a recent issue of the *Journal du Conseil*, BAGENAL (1959) derives some figures for the difference in catching power of trawls with and without Vigneron-Dahl gear which are truly remarkable. For instance, in his series B, the V.D. gear caught 68 times as many plaice as the otter trawl, though the distances between the trawl doors, and hence probably the potential area swept by the two trawls, are in the ratio of only about 3:1 (the exact value cannot readily be deduced from his data). The ratios obtained are also well outside the values given by BOWMAN (1932) and HICKLING (1931), of about 1·5:1 and though their figures are not in a form suitable for rigorous statistical analysis, BOWMAN, in some dozens of independent estimates for haddock, obtained as extreme values 0·6:1 and 4·9:1, so that the discrepancy between them and BAGENAL's figures of 8·8:1, 8·7:1, etc. does not need a test of significance. Though of course BAGENAL's experiments were not specifically designed to obtain a figure for the ratio of catches of commercial trawlers with and without V.D. gear, they are apparently suitable for such a comparison and therefore to prevent uncertainty in the interpretation of past commercial statistics it seems desirable to attempt to resolve in part the discrepancy between BAGENAL's and BOWMAN's figures.

The study of the effects of major changes in gear, e. g., V.D. bridles, has been made more difficult by the fact that apparently small differences in the rigging or handling of the gear can make vast changes in the catches — it is these differences, of course, which in a large part distinguish the good and indifferent fishermen. These effects are most likely to be serious when only one ship is concerned, a research ship being perhaps particularly vulnerable because there is not the urgent economic pressure to keep her fishing efficiency up to a maximum. A possible explanation of the discrepancy between BAGENAL's and BOWMAN's results is that BAGENAL's otter trawl was relatively inefficient. The relative catching power of the otter trawl on plaice, though low in all experiments was much less in 1956–57 than in 1952–53, as shown in the following table: —

Date	V.D./O.T.	Date	V.D./O.T.
25.8.52	4·46	29.10.56	131·00
1.9.52	10·43	30.10.56	84·00
27.4.53	11·42	31.10.56	48·00
4.5.53	11·63	1.11.56	115·00
		2.11.56	26·00
		31.10.57	29·40

As my colleague Mr. MARGETTS has suggested, a possible explanation for the low catches of flatfish by the otter trawl lies in the attachment of the groundrope. For the V.D. gear the point of attachment is the foot of the bridle, i. e., ground level, and the groundrope will touch the bottom for all its length. For the otter trawl the point of attachment on the trawl door was off the bottom, so that some, if not most, of the groundrope was off the bottom, thus reducing the catch of flatfish. It seems therefore that the conversion factor obtained by BOWMAN and HICKLING (1·5:1) should be used in adjusting past commercial statistics.

BAGENAL's interpretation of the day and night differences between V.D. and otter trawl also appears incorrect. For each day and species he carried out an analysis of variance (e. g., Table 6) and found that the Gear × Time inter-action was generally not significant, and concluded, correctly, that such daily data did not prove that the V.D. gear was relatively more efficient in the daytime. In the discussion and summary this is apparently incorrectly taken as equivalent to proving that V.D. gear was equally efficient at day and night. In fact his data support, though perhaps do not prove, the theory that V.D. gear is better in daylight. For all hauls of series A taken together, the ratios of V.D. to otter trawl in day and night are: —

	Day	Night
Cod	9·0	4·5
Haddock	7·7	6·3
Plaice	19·6	5·2
Whiting	4·3	2·4
Witch	19·1	12·9
Long Rough Dab	6·1	5·5
All Species	7·4	5·1

As there is strong evidence that the otter trawl as used was inefficient there is at least the possibility, on these data, that the relatively better V.D. catches at night were not caused by the bridles at all, and that the bridles might be only effective in daylight, when the fish can see them.

BAGENAL's paper should revive interest, on the general question of solving the problem of how the V.D. gear obtains its greater catch (be it 50% or twenty times greater), but it seems that this problem (like that of the action of the warps of a seine net) will only be solved by direct observation of the fishes' behaviour.

J. A. Gulland,
Fisheries Laboratory,
Lowestoft.

OUR O.T. gear may indeed be inefficient at catching flatfish. In choosing the figures for plaice, Mr. GULLAND has taken the most extreme given in my paper, and it must be remembered that the V.D./O.T. ratios for round fish also tend to be very much larger than those found by BOWMAN and HICKLING. For example, in series B, the V.D. gear caught over three times as many cod, six times as many haddocks, and nearly twice as many whiting as the O.T.

gear. This will need a separate explanation if we accept that the flatfish figures are due to O.T. gear inefficiency.

I do not believe that the attachment of the groundrope is very different in our O.T. and V.D. trawls. With the O.T. gear the back strops of the otter board were shackled to the wing of the net, and the attachment of the lower back strop (which went to the footrope) was six inches above the bottom of the otter board. With the V.D. trawl the centre of the hole in the dan leno, through which the lower dan leno back strop passed to the footrope, was also six inches from the bottom, so that any difference in this respect between the two types of trawl was probably negligible; or indeed the reverse of Mr. MARGETTS's suggestion may hold, since the extra weight of the otter board near the wing of the net would tend to keep the footrope closer to the bottom.

Mr. GULLAND's criticism of my wording of the interpretation of the null hypothesis is justified.

If the fish see the bridles, the V.D. gear should be very much less efficient at night than during the day. A reduction in the V.D.: O.T. ratio of from 7:1 by day to 5:1 by night indicates that something other than sight is involved.

A recent paper by ZUPANOVIC and GRUBISIC (1958) may be significant in this connexion. From the English summary and table headings it appears that comparable hauls were taken with V.D. gear fitted with ordinary steel wire bridles and with combination (wire and manila) bridles. The differences in composition of the catch, and the length distributions of the fish, are said to be significantly different. While it is easy to understand how the two materials might set up different vibrations in the water, it is much harder to believe that these materials look different to the fish. Experiments on these lines, using bridles of different circumference, are now being carried out at Millport.

Finally my aim was, and still is, to revive interest in how V.D. gear works. If, as Mr. GULLAND suggests, this aim will be achieved, I shall feel that my contribution has been worthwhile.

T. B. Bagenal,
Marine Station,
Millport.

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Review

G. C. Trout. "The Bear Island Cod: Migrations and Movements." Fish. Invest. Lond., Ser. 2, **21** (6). 1957.

While the spawning migration of the arctic cod is reasonably well known, little information has up till now been available of the movements and ways of the immature part of this important fish stock. It is generally assumed that in the immature stage the arctic cod is more or less completely divided into two subpopulations, one inhabiting the central and south-eastern Barents Sea and the other found in the Svalbard waters, of which the Bear Island grounds are the most important. Although TROUT's paper is mainly concerned with the Bear Island stock it also reflects upon the life history of the whole population, both mature and immature.

Most of the basic data of the paper is drawn from the work with the research vessel "Ernest Holt" in the years 1949–56. Three main sources of information have been used to elucidate the life of the young Bear Island cod, viz.: (1) analysis of otolith structures, (2) tagging experiments, and (3) more direct observations concerning the distribution and behaviour of the fish derived from fishing (both "Ernest Holt's" results and reports from commercial trawlers).

Three types of otoliths with different internal structures are described. The relative proportion of these types are shown to be different in different parts of the Svalbard area indicating that the otolith structures are related to local environmental conditions, and that the mixing of the stock is not a complete one. This method is thus an aid in the study of the geographical segregation of the population.

Recaptures from extensive tagging experiments in 1951 and 1952 are shown in detailed charts. They relate local migrations within the area as well as farther wanderings most of which are no doubt associated with the spawning on the Norwegian coast. The recoveries in the Svalbard waters indicate a seasonal migration pattern which is in general agreement with experience from practical fishing: an advance northwards in summer and a return in late autumn to the Bear Island Banks and further south. The shallow Spitsbergen Bank which connects Bear Island with the more northern islands in the Svalbard group seems to direct the migrations along the two main routes following its western and eastern slopes, thus leading the fish to the well known fishing grounds along the West Spitsbergen in the west and around Hope Island in the east.

One chapter of the paper deals with the depth distribution of the cod. The basic data are derived from W/T reports from commercial vessels received on board the "Ernest Holt" during her cruises 1949–51. There is a clear annual

pattern in the depths fished by the vessels, shallow in late summer and deep in winter. Some similar data from the south-eastern Barents Sea show a less pronounced change during the year. It is assumed that this change in fishing practice reflects an annual vertical movement of the main stock of marketable fish in the area. Observations on echo-sounders of pelagic occurrence of cod are also mentioned. It is thought that the pelagic stage is primarily a summer behaviour of the cod in response to light and food organisms.

Some further observations of the fish and its environment are put forward in order to build up a comprehensive picture of the movements and migrations. Thus an annual feeding curve is constructed based on observations of the stomach contents in samples of "Ernest Holt's" catches. These data show a lower feeding in winter than during the rest of the year. The special light conditions in these high latitudes are believed to have an important influence on the behaviour of the cod. It is shown that during three to four winter months the fish in the deeper waters must be considered to be entirely without light both day and night.

The main thesis of the paper is that the vertical movement and the horizontal migrations of the fish are closely associated and can be explained as responses to the changing conditions of light and feeding and to the ocean current. The summer migration to the north is a passive drift with the current at a time when the cod shoals are largely pelagic. The winter migration, on the other hand, takes place on the bottom in the absence of light and is an active swimming against the current (rheotaxis). In favour of this theory it is shown that all known geographical limits of fishing on the northern grounds in summer are within a reasonable estimate of the possible distance of passive transport by the water masses. This interpretation is a very interesting one and has many plausible features. But some points seem to be in need of further verification before the theory can be generally accepted.

The paper should be especially recommended for the broad range of subjects which are drawn into the discussion. The extensive bibliography, which is included, will no doubt also prove of value to other workers in this field. As the author is still engaged in investigations of the arctic cod we shall look forward to further important contributions from him on the same subject.

G. Sætersdal

Current Bibliography

Prepared by A. R. Margetts

Note. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

Subscribers and those on the distribution list will receive regularly upon application to the General Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

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When considering the rapid increase in our knowledge it is inevitable that a book like the present one already at appearance is not fully up-to-date, but as a status quo of our knowledge of today it is of lasting value. A vast amount of material has been made easily accessible, and of great importance are the many summaries of current discussions and diverging opinions. A multitude of questions remain, however, unsolved and many gaps in our knowledge are still to be filled. The ample incitement to further studies is one of the great advantages of this work.

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